ing trees, or they can be picked by hand or clipped with a pruning pole from the branches. The fruits are mature when they have turned black (Rashid 1975). Accumulating quantities of maga seeds is more difficult. Maga fruits can be clipped from the trees when they reach full size (no color change is observed). Fruits that are still hard should be left for 2 or 3 days and will continue to ripen. If not eaten by bats and birds, the fruits fall soon after ripening and can be picked up from the ground. Because bats and birds drop the seeds as they consume the fruits, seeds can be collected from the ground under bearing trees or beneath nearby perch trees. Good seeds have a cinnamon-brown color with a waxy luster and are free of fungal spots. Lighter or darker colors denote immaturity or overmaturity and loss of viability (Marrero 1949). Nursery workers normally clean the seeds by hand, a fairly rapid process. Cleaning with macerators may not be possible due to the fragile nature of the seeds, especially those of maga. Seeds of portiatree are apparently recalcitrant but somewhat resistant to drying and can be stored in sealed containers for weeks to months under refrigeration (4 °C). The seeds of maga are highly recalcitrant. The folded cotyledons (figure 2) are active and turn green within the seed as germination begins. The seeds begin germinating 5 to 7 days after the fruit ripens (Francis 1989). Many of the seeds picked up from the ground, either loose or within rotting fruits, already have the radicle exposed. It is best to place moist paper towels or other moistened material in the collection container and sow the seeds as soon as possible. Viability of maga seeds can be extended to nearly 4 months by drying to 62.5% moisture and storing at 2 to 4 °C (Marrero 1942).

Germination. No pregermination treatments are necessary. Seeds of portiatree should be sown in sandy media and lightly covered (Parrotta 1994). From 65 to 79% of fresh seeds germinate, beginning in 8 days and continuing over a 9-week period (Francis and Rodríguez 1993; Ricardi and others 1977; Parrotta 1994). Maga seeds may be sown and lightly covered in ordinary potting mix. Marrero (1942) reported that, although 70 to 80% of fresh seeds germinated, only 20% of seeds stored at room temperature for 2 weeks germinated. Francis and Rodríguez (1993) reported 80% germination beginning 6 days after sowing. Germination of both species is epigeal (figure 3) (Francis 1989; Parrotta 1994).

Nursery practice. Ordinary nursery practice is to germinate seeds in germination trays or beds and transplant seedlings into containers (pots or plastic nursery bags) after the first true leaves emerge. Portiatree seedlings reach 15 cm (6 in) in height about 3 months after sowing (Parrotta 1994). Moving portiatree seedlings into full sunlight after they are established in the pots is recommended. Rooted cuttings are also used to produce portiatree stock. Maga seedlings develop rapidly in partial shade, reaching 20 cm (8 in) in 3 months and 40 cm (16 in) in 6 months (Francis 1989). Maga seedlings should be moved into full sun a few weeks before outplanting. Seedling stock of either species from 15 to 50 cm (6 to 20 in) can be used to establish plantations. Trees destined to become ornamentals are often grown in pots until they attain 1 to 2 m (39 to 79 in) in height. Wildlings are sometimes collected, potted, and allowed to rebuild their root system before outplanting.

Figure 2—*Thespesia grandiflora*, maga: seed cut in longitudinal section.

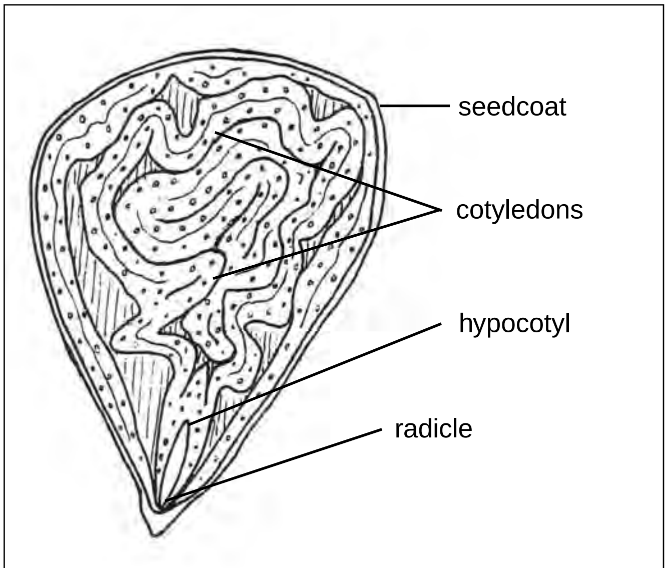
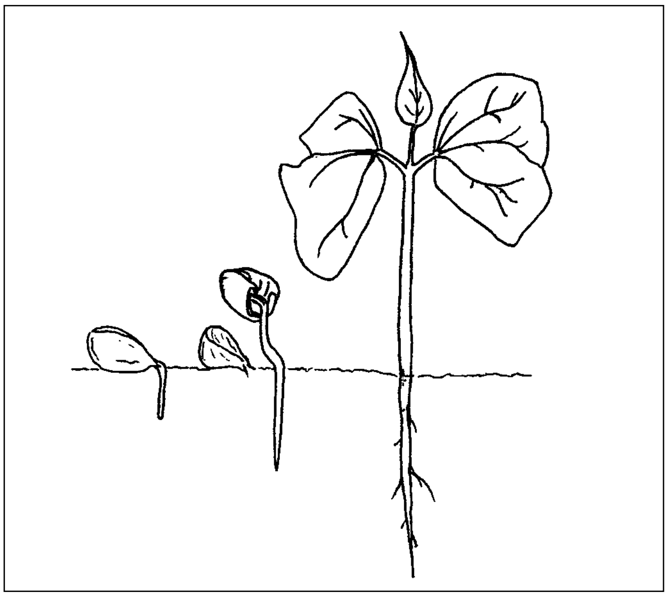


Figure 3—*Thespesia grandiflora*, maga: germination and seedling development.



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Cupressaceae—Cypress family

Thuja L.

arborvitae

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Growth habit and occurrence. The arborvitae genus—*Thuja*—includes 2 species native to North America and 3 or 4 (depending on the authority consulted) Asian species (table 1). All individuals in the genus are aromatic, evergreen trees, but some species also have shrubby forms.

Mature northern white-cedars are medium-sized trees, usually 12 to 15 m tall and 60 to 90 cm in dbh (Harlow and others 1991). The rooting habit of mature trees is usually shallow and spreading. In addition to regeneration from seeds, vegetative reproduction by layering is common where there is sufficient moisture (Johnston 1990). Northern white-cedar grows on a wide variety of organic and mineral soils but does not develop as well on extremely wet or extremely dry sites (Johnston 1990). However, most commercial stands of northern white-cedar are in swamps. Geographical range for the species extends from Nova Scotia to Maine and westward to Manitoba and Minnesota. Isolated stands occur in west-central Manitoba, northern Ontario, southern Wisconsin, northern Illinois, Ohio, Massachusetts, Connecticut, and the Appalachian Mountains as far south as Tennessee (Little 1971).

Western redcedar can grow into large trees, especially in stream bottoms, moist flats, and gentle, north-facing slopes at low elevations (Curran and Dunsworth 1988; Schopmeyer 1974). It will grow to 45 to 60 m tall and 120 to 240 cm in dbh (Harlow and others 1991). Western redcedar develops extensive roots with a dense network of fine roots (Minore 1990). As in northern white-cedar, vegetative reproduction in western redcedar is common and provides the dominant means of regeneration in some stands. Branch layering, rooting of fallen branches, and rooting of branches attached to fallen trees have all been reported (Minore 1990). Western redcedar grows on many different soils and at a wide range of elevations. Its native range includes the Pacific Coast from northern California to southeastern Alaska; the Cascade Mountains in Oregon and Washington; and the Rocky Mountains in southeastern British Columbia, northeastern Washington, northern Idaho, and western Montana (Little 1971).

Table 1—*Thuja,* arborvitae: nomenclature and occurrence

Scientific name & synonym(s)	Common name(s)	Occurrence
***T. occidentalis* L.** *T. obtusa* Moench *T. odorata* Marshall	**northern white-cedar,** white-cedar, eastern arborvitae, swamp-cedar, arborvitae, eastern white-cedar	Nova Scotia to Maine & W to Minnesota & Manitoba; S in Illinois, Ohio, & New York; locally in Appalachian Mtns.
***T. plicata* Donn ex D. Don** *T. plicata* D. Don; *T. plicata* Donn *T. plicata* Donn ex D. Don in Lamb. *T. gigantea* Nutt. *T. menziesii* Dougl. ex Endl. *T. lobbii* Hort. ex Gord.	**western redcedar,** Pacific redcedar, giant-cedar, arborvitae, giant arborvitae, canoe-cedar, shinglewood	Pacific Coast region, from SE Alaska to N California, Cascade Mtns. in Washington & Oregon, Rocky Mtns in British Columbia, N Idaho, & W Montana
***T. standishii* (Gord.) Carr.** *T. japonica* Maxim. *Thujopsis standishii* Gord.	**Japanese thuja,** Japanese arborvitae	Japan
***T. koraiensis* Nakai** *T. kongoënsis* Nakai	**Korean thuja,** Korean arborvitae	Korea
***T. sutchuensis* Frachet**	**Sichuan thuja**	China

Sources: Cope (1986), Kartesz (1994a&b), Little (1979), Rushforth (1987), Vidakovic (1991).

The 3 Asian species listed (table 1) are only planted for ornamental purposes in the Untied States. Korean thuja reaches a height of 11 m, and Japanese thuja may grow as tall as 15 m (LHBH 1976).

Use. Both native species are valuable timber trees because their heartwood is light in weight and resists decay. The wood is used extensively for shingles, shakes, siding, and poles. Young northern white-cedar and the crowns of felled trees are browsed extensively by deer (Schopmeyer 1974). Many horticultural varieties of arborvitae with distinctive growth forms and foliage colors are propagated vegetatively for ornamental use (Cope 1986; Dirr 1990; Rushforth 1987; Vidakovic 1991). Northern white-cedar is commonly used as a root stock for horticultural grafts of *Thuja* spp. (LHBH 1976). Extractives from western redcedar inhibit the growth of numerous bacterial and fungal species (Minore 1983).

Geographic races and hybrids. Although no naturally occurring races or hybrids of northern white-cedar or western redcedar have been reported (Kartesz 1994a; Vidakovic 1991), a hybrid between western redcedar and Japanese thuja has been produced (Minore 1990; Vidakovic 1991).

The many horticultural varieties of northern white-cedar and western redcedar suggest that these 2 species have considerable genetic variability. However, variation in growth and survival has not been demonstrated by all provenance tests. Northern white-cedar provenance tests demonstrated some differences in height growth rates but not consistent differences in survival rates (Jeffers 1976; Jokela and Cyr 1979). Based on their provenance work, Bower and Dunsworth (1988) concluded that western redcedar has little genetic variability. In contrast, Sakai and Weiser reported differences in frost-tolerance for western redcedar (1973).

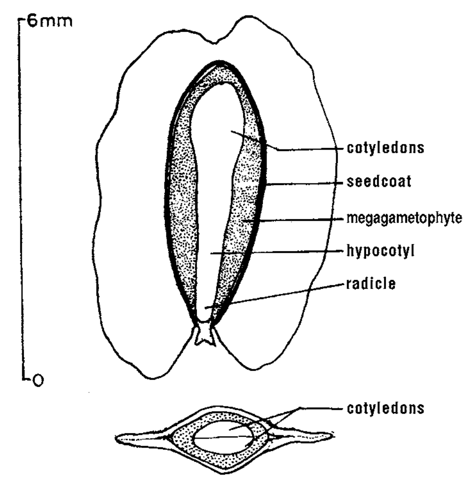
Flowering and fruiting. Male and female flowers are borne on the same tree but usually on separate twigs or branchlets (Schopmeyer 1974). Flower initiation begins in spring to early summer, development ceases in the fall, pollen is shed in late winter to early spring, and fertilized cones are mature by fall (Owens and Molder 1984). Female flowers form near the tips of vigorous lateral branches (figure 1) and are usually higher on the tree than the male flowers. The presence of low numbers of cone buds in the dormant season indicates that a poor cone crop will follow in the fall (Owens and Molder 1984). Cones of both native and Asian species are about 8 to 12 mm long (Little 1976; Schopmeyer 1974). Western redcedar cones have 5 to 6 pairs of scales. The 3 middle pairs are fertile and contain 2 to 3 seeds (Owens and Molder 1984). Cones of northern white-cedar have 4 to 5 pairs of scales with the middle 2 or 3 pairs fertile (Briand and others 1992). Each fertile scale contains 2 seeds. During the ripening period, cones change in color from green to yellow and finally to a pale cinnamon brown. Depending on location, cones are ripe in August or September (Schopmeyer 1974). Their light chestnut-brown seeds are 3 to 5 mm long and have lateral wings about as wide as the body (figures 2 and 3). Embryos of both species have 2 cotyledons.

Collection of cones. Trees as young as 10 years old have produced cones (Curtis 1946; Edwards and Leadem 1988), but heavy cone production usually occurs only on older trees. Cones may be picked by hand from standing or recently felled trees, or the cones maybe flailed or stripped onto a sheet of canvas, burlap, or plastic. Cones of western

Figure 1—*Thuja*, arborvitae: mature cones of *T. occidentalis*, northern white-cedar, with female cone buds on branch tips above the brown mature cones.

Figure 2—*Thuja*, arborvitae: mature cones and seeds of *T. occidentalis*, northern white-cedar.

Figure 3—*Thuja occidentalis*, northern white-cedar: longitudinal section **(top)**, and transverse section showing 2 cotyledons **(bottom)**.



redcedar have been harvested with aerial rakes attached to helicopters (Edwards 1986; Wallinger 1986). A good time for collection is when seeds have become firm and most of the cones have turned from yellow to brown. For northern white-cedar, the period between cone ripening and start of cone opening is only 7 to 10 days (Schopmeyer 1974). Cones of western redcedar also start to open soon after they ripen. Owens and Molder (1984) recommend collecting cones in late August to early September. Peak rate of seed-fall from both species occurs about 4 to 6 weeks after the first cones have opened (Schopmeyer 1974). Mature trees of both species produce cones prolifically every 3 to 5 years, but all cones do not open at the same time. Seed release therefore progresses slowly. Substantial seed yields probably can be obtained from cones collected as late as 1 month after the first cones have opened.

Extraction, cleaning, and storage of seeds. Seeds can be extracted from cones by air-drying for 1 to 3 weeks (VanSickle 1994) or cones may also be spread out to sun-dry. Kiln-drying is more efficient for large quantities of cones. Cones of northern white-cedar have been opened by exposing them for 4 hours in an internal-fan-type kiln at a temperature of 54 °C and a relative humidity of 38% (Schopmeyer 1974). Kiln temperatures below 43 °C are preferred, however, to prevent damage to the seeds (Schopmeyer 1974). Western redcedar cones were opened in 24 to 36 hours at a temperature of 33 °C (Edwards 1986), 18 to 20 hours at 41 °C (Owens and Molder 1984), or 27 °C for 12 hours (Henchell 1994). Higher temperatures increase the probability that seeds will be damaged. After cones have opened, seeds are extracted in a mechanical cone shaker or tumbler and separated from the cone scales by fanning or gravity separation. Seeds should not be de-winged (Edwards and Leadem 1988; Gordon and others 1991).

The number of fully developed seeds in each cone can vary dramatically. As few as 2 to as many as 12 (average 7.7) fully developed seeds were counted in northern white-cedar cones (Briand and others 1992). For western redcedar, cones from natural stands contained an average of 2.6 filled seeds/cone, whereas cones from seed orchards contained an average of 6 fully developed seeds per cone (Colangeli and Owens 1990). One kilogram of cleaned northern white-cedar seeds contains an average of 763,000 seeds (346,000/lb) (Schopmeyer 1974). The average number of cleaned western redcedar seeds reported is 913,000/kg (414,000/lb) (Schopmeyer 1974). Empty seeds can be readily separated from full seeds in a seed aspirator or blower.

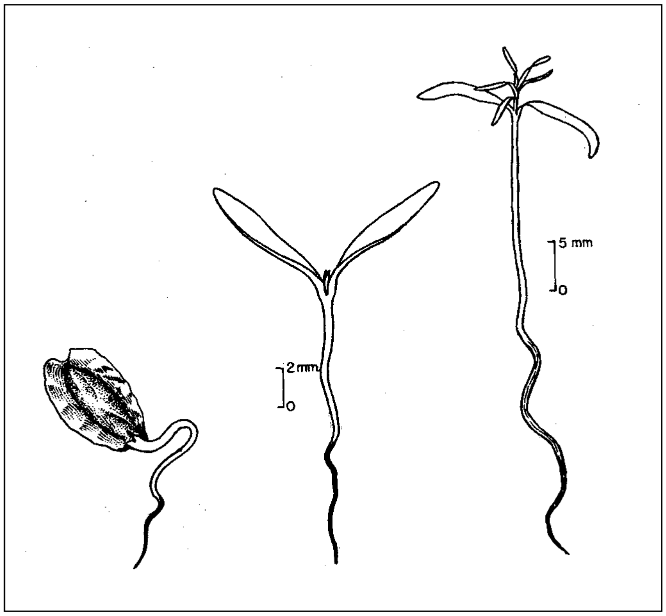
Arborvitae seeds are orthodox in storage behavior. Seeds should be stored in fiber containers with plastic or foil liners (Gordon and others 1991). Seeds stored at a moisture content of 5 to 10% in sealed containers at 0 to 5 °C should remain viable for up to 5 years (Gordon and others 1991). For longer periods, storage at –18 °C is recommended.

Pregermination treatments. The need for stratification to ensure that a high percentage of seeds germinate uniformly is not clear. Some authors state that stratification is not needed. Others recommend stratification for 30 to 60 days in moist medium at 1 to 5 °C (Henchell 1994; Schopmeyer 1974). Dirr and Heuser (1987) report that 2 weeks of stratification will improve germination of Japanese thuja. Germination of northern white-cedar and western redcedar seeds is tested by placing seeds on top of moist germination paper kept at 20 to 30 °C; no pretreatment is recommended. Germination is epigeal (figure 4). The first count of germinated seeds is made after 7 days and the last count after 21 days (ISTA 1993).

Nursery practice and seedling care. Northern white-cedar and western redcedar seedlings are not produced in large numbers but can be grown in both bareroot nurserybeds and in containers. Many ornamental varieties of arborvitae, both native and Asian, are propagated from cuttings or by layering (Dirr and Heuser 1987). Cultural practices vary by nursery.

The irregular shape and small size of western redcedar seeds make it difficult to sow the seeds mechanically. Coating seeds with fine-textured materials such as clay, sand, charcoal, or peat has been attempted to make the seeds more uniform in size and shape (Edwards and Leadem 1988). This process should be done just before sowing,

Figure 4—*Thuja occidentalis*, northern white-cedar: seedling development at 1, 5, and 25 days after germination.



because seed viability is reduced if seeds are stored after being coated (Edwards and Leadem 1988).

In bareroot nurseries, seedlings are grown as 1+1, 2+0, 2+1, and 3+0 stock. Fall-sowing is preferred for northern white-cedar and spring-sowing for western redcedar. Some nurseries soak seeds in water for 24 to 48 hours and then stratify them for 7 to 60 days at 2 °C before sowing. Because of better mycorrhizal colonization, planting western redcedar seeds in nurserybeds that have not been fumigated for 1 year seems beneficial (Henchell 1994). Average seedbed density for western redcedar is about 500 seedlings/m^2 (46/ft^2) but varies from 240 to 1000/m^2 (22 to 93/ft^2) (Edwards and Leadem 1988; Henchell 1994). The wider spacings may produce higher quality seedlings (van den Driessche 1984). Sowing depth varies from 0.3 to 1.0 cm ($^1/_8$ to $^3/_8$ in) (Schopmeyer 1974). In another approach used in Minnesota, VanSickle (1994) sowed northern white-cedar seeds at 0.15 cm ($^1/_{16}$ in) and covered them with a double layer of hydromulch. Western redcedar seeds have also been sown on the surface, pressed into the soil by the packing roller of a seed drill, and covered immediately with shade material (Henchell 1994). First-year northern white-cedar seedlings are grown both with half-shade (Jones 1994) and without shading (VanSickle 1994). Shading (50 to 70%) is recommended for first-year western redcedar seedlings. Soil moisture needs to be monitored closely because seeds and seedlings of western redcedar are sensitive to drying (Henchell 1994).

Container seedlings have become more common in the last decade and can be produced in 1 or 2 years. Various container sizes are used, depending on the desired size of the outplanted stock. Common container volumes used are 66 to 164 ml (4 to 10 in^3) (Olson 1994; Schaefer 1994). Seedlings of northern white-cedar grown from fall-planted seeds are ready for outplanting in May, unless the larger containers are used. Seedlings of western redcedar grown from spring-planted seeds are ready for outplanting in the fall or following spring. Seedlings in larger containers are grown in the greenhouse for 10 to 18 months before out-planting. Seeds sown in the containers are covered with a thin layer (about 0.3 cm, or $^1/_8$ in) of crushed granite (Olson 1994) or quartz (Schaefer 1994). Western redcedar seedlings grown in containers and chemically root pruned by painting the inside of the container with latex paint containing copper carbonate showed good height and volume growth when outplanted (Curran and Dunsworth 1988). In container-grown western redcedar, a mild nitrogen and moisture stress after the seedlings reach 8 to 10 cm (3 to 4 in) produces hardened stock with a balanced root to shoot ratio (Schaefer 1994). Seedlings grown for 1 year in containers and then transplanted to the nursery bed (plug+1 transplants) are well-balanced and have been successful when outplanted (Ramirez 1993).

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Tiliaceae—Linden family

Tilia L.

linden or basswood

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Growth habit, occurrence, and uses. The genus *Tilia* L.—linden or basswood—consists of about 40 species of large or medium-sized, deciduous trees that are indigenous to the temperate Northern Hemisphere. *Tilia* is the only genus of its family, Tiliaceae. Species reach their maximum size in loamy, moist, fertile soil, but they tolerate poor soils, pollution, windy conditions, and transplanting and can be grown in full sun or partial shade (Dirr 1990; Haller 1995; Kunneman and Albers 1991). Lindens possess a well-developed root system and are long lived, with some species living between 500 to 1,000 years (Haller 1995; Kunneman and Albers 1991). Table 1 lists species native to North America as well as widely grown non-native species.

Few shade trees vary so greatly in shape, leaf size, and growth rate as do the lindens (Flemer 1980). They generally possess a uniform globular crown and smooth, silver-gray bark that becomes fissured on old trees (table 2). The winter form is striking, with stiff, erect branches growing upward at 30° angles from a thick trunk (Burgess 1991). Considerable differences in growth habit exist among cultivars of littleleaf linden, ranging from the very dense, formal pyramidal habit of 'Greenspire', the dense upright oval shape of 'Chancellor', to the more open, informal oval habit of 'Fairview' (Pellett and others 1988).

There is much disagreement among taxonomists as to correct identification of species, and there are numerous names in the literature that are no longer recognized by many botanists. For example, *T. monticola* Sarg. and *T. michauxii* (Nutt.) Sarg. are sometimes seen in the literature or listed as specimens in botanical gardens, but they are now considered to be varieties of white basswood—*T. americana* var. *heterophylla* (Venten.) Loud.—recognized previously as *T. heterophylla* Venten. (Ayers 1993; Rehder 1990).

Table 1—*Tilia,* linden: nomenclature, and occurrences

Scientific name & synonym(s)	Common name(s)	Occurrence
***T. americana* L.** *T. glabra* Venten.	**American linden,** basswood, whitewood, American lime, bee-tree	New Brunswick S to Virginia & Texas
***T. americana* var. *caroliniana* (P. Mill.) Castigl.**	**Carolina basswood**	SE US
***T. americana* var. *heterophylla* (Venten.) Loud.**	**white basswood**	West Virginia to Florida, W to Indiana & Alabama
***T. cordata* P. Mill.** *T. parviflora* J. F. Ehrh. ex Hoffm.)	**littleleaf linden,** small-leaved lime, European linden	Europe
***T. euchlora* K. Koch** *T. cordata* x *T. dasystyla*	**Crimean linden,** Caucasian lime	SE Europe & SW Asia
***T. europaea* L.** *T. cordata* x *T. platyphyllos* *T. intermedia* DC. *T. vulgaris* Hayne	**European linden,** common linden, lime	Europe
***T. mexicana* Schldl.**	**Mexican basswood**	Mexico
***T. petiolaris* DC.**	**pendent silver linden,** pendent white lime, weeping lime	SE Europe & W Asia
***T. platyphyllos* Scop.** *T. europaea* var. *grandiflora* Hort.	**bigleaf linden,** large-leaved lime, largeleaf linden	Europe to SW Asia
***T. tomentosa* Moench** *T. argentea* DC.	**silver linden,** European white linden	SW Europe & Asia

Sources: Dirr (1990), LHBH (1976), Plotnik (2000), Rehder (1990), RHS (1994).

Table 2—*Tilia,* linden: growth habit and general comments

Species	Growth habit & maximum height	General comments
T. americana	Tree to 40 m with numerous, slender, low-hung spreading branches; pyramidal when young, crown somewhat rounded at maturity	Flowers pale yellow in summer; bee plant; wood used for making expensive furniture & excelsior, inner bark used for fabric
T. a. var. *caroliniana*	Tree to 20 m; close to habit of *T. americana*	—
T. a. var. *heterophylla*	Tree to 30 m; crown conical	—
T. cordata	Tree to 30 m; pyramidal when young; upright-oval to pyramidal-rounded & densely branched in old age; crown outspread	Widely planted as a street tree; pollution-tolerant; excellent shade tree
T. euchlora	Tree to 20 m	Similar to *T. cordata*
T. europaea	Tree to 37 m	—
T. mexicana	Tree to 20 m	—
T. petiolaris	Tree to 23 m	Sometimes considered as a pendulous selection of *T. tomentosa*
T. platyphyllos	Tree to 40 m; crown conical to broadly conical	Not widely planted in the US
T. tomentosa	Tree to 27 m; pyramidal when young; upright-oval to pyramidal-oval in later years; crown dense	Can be grown effectively as a multi-stemmed specimen to highlight light gray, smooth bark; good street tree, tolerating heat & drought better than other lindens

Sources: Dirr (1990), LHBH (1976), Plotnik (2000), Rehder (1990), RHS (1994).

Lindens are generally not suitable for lumber because the wood is soft and rots easily. However, the soft, straight-grained and even-textured wood is ideal for woodcarving and is utilized to make musical instruments, piano keys, Venetian blinds, and veneer and can serve as a source of fiber (Haller 1995; Kunneman and Albers 1991). The wood does not produce splinters, thus making it ideal for tool handles. The inner bark (or "bast") consists of long, tough fibers that once were used in the production of cordage, mats, and clothing. The common names for the species—basswood, linden, and lime—are derived from this characteristic: *bast* gives us the name bastwood or basswood; *linden* and *lime* are thought to be derived from the Latin word for linen (Haller 1995). In addition, flowers of linden are quite fragrant and produce large quantities of nectar that is very attractive to bees. The flowers of European, bigleaf, and littleleaf lindens are brewed for tea (Bremness 1994). The nectar of some species is so overpowering that bees can be found inebriated on the ground beneath the tree (Haller 1995). The light-colored honey produced is world famous.

Lindens are used primarily as ornamental shade and street trees (table 2), more so in Europe than in the United States. For example, Berlin's most famous boulevard is named *"Unter den Linden"*. They are well-adapted to a broad range of soil and climatic conditions and are relatively free of major disease problems that may threaten the survival or landscape value of established trees (Pellett and others 1988). The European lindens—littleleaf, European, bigleaf, and silver lindens—have greater importance in landscape plantings in the United States because they are more tolerant and ornamental than American species such as American linden (Dirr 1990; Heit 1977). In addition, American linden becomes too large for the average home property and is better left in the forest (Dirr 1990). However, silver linden possesses a shallow root system and its canopy casts dense shade, making it unsuitable for underplanting (Burgess 1991).

Geographic races and hybrids. As mentioned previously, there is much disagreement among taxonomists as to correct identification of species. For example, there is debate whether white basswood is a southern race of American linden or a separate species. Also, hybridization between species occurs naturally and has given rise to variability among seedlings (Kunneman and Albers 1991). Of the more common hybrids, Crimean and European lindens are not considered superior landscape trees relative to littleleaf linden (Dirr 1990).

Flowering and fruiting. Perfect, fragrant, yellowish or whitish flowers that bloom in June or July are borne in short, pendulous cymes with stalks attached to a large thin-textured oblong bract. Trees and clonal groups of trees flower almost simultaneously over the exposed parts of their crowns. In each inflorescence, the terminal flower of the dichasium opens first and in warm weather is followed at intervals of a day by flowers on the branches of successive orders (Pigott and Huntley 1981). Trees usually flower within 5 to 15 years when grown from seed. Shortness of blooming period (several days to 2 weeks, depending on weather conditions) and lack of consistent flowering from year to year are problems for beekeepers harvesting honey (Ayers 1993). In particular, the American lindens have a reputation for not flowering every year. Some of the introduced species are more consistent (Ayers 1993).

Following pollination, temperatures must be > 15 °C for growth of the pollen tube and for fertilization to occur so that fruits will be produced (Pigott and Huntley 1981). Fruits are grayish, nut-like, round to egg-shaped capsules that mature in autumn but may persist on the tree into the winter. Each consists of a woody pericarp enclosing a single seed (but sometimes 2 to 4 seeds) (figures 1 and 2) (Brinkman 1974; Pigott and Huntley 1981). The pericarp consists of an outer layer of loose fibers forming a mat (or tomentum) and a broad region of thick-walled lignified fibers that are responsible for its hard, tough, woody character (Spaeth 1934). Fruits of American linden are tough and leathery, whereas those of littleleaf linden tend to be thinner and rather brittle (Heit 1967). Seeds possess a crustaceous seedcoat; a fleshy, yellowish endosperm; and a well-developed embryo (figures 2 and 3). Natural dispersion is primarily by wind and animals (Brinkman 1974).

Collection of fruits, seed extraction and cleaning. The ideal time to harvest fruits is early fall, when seed moisture content is approximately 16% (Vanstone 1982). During fruit ripening, moisture is lost from the seeds at a rate of 1 to 2% per day, so that seeds must be monitored closely. Pericarp color is a reliable indicator of moisture content in relation to germination. Fruits should be picked when the pericarp is turning from green to grayish-brown and before the pericarp becomes tough and leathery. Otherwise, seeds will require greater efforts during extraction and scarification. There is generally uniform ripening on any individual tree, but the exact date of ripening may vary by several weeks among trees (Vanstone 1978). Because fruits of lin-

Figure 1—*Tilia*, linden: fruits of *T. americana*, American linden (**top**) and *T. cordata*, littleleaf linden (**bottom**).

Figure 2—*Tilia cordata*, littleleaf linden: seed.

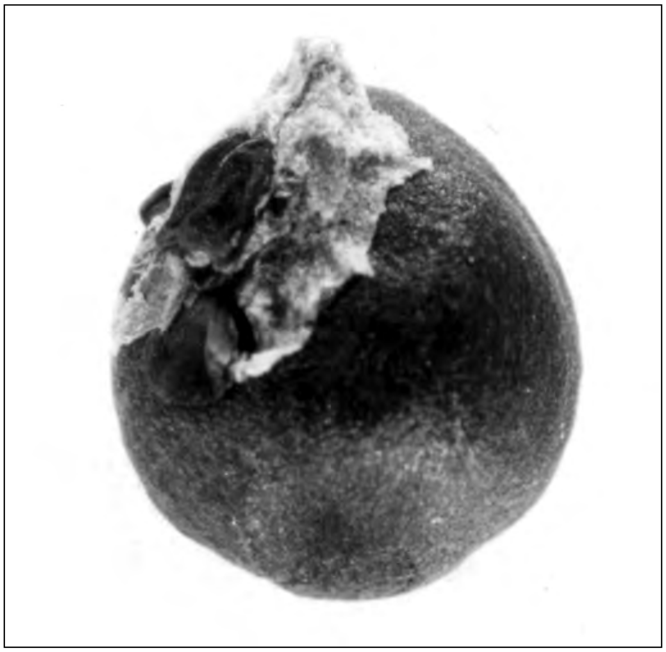
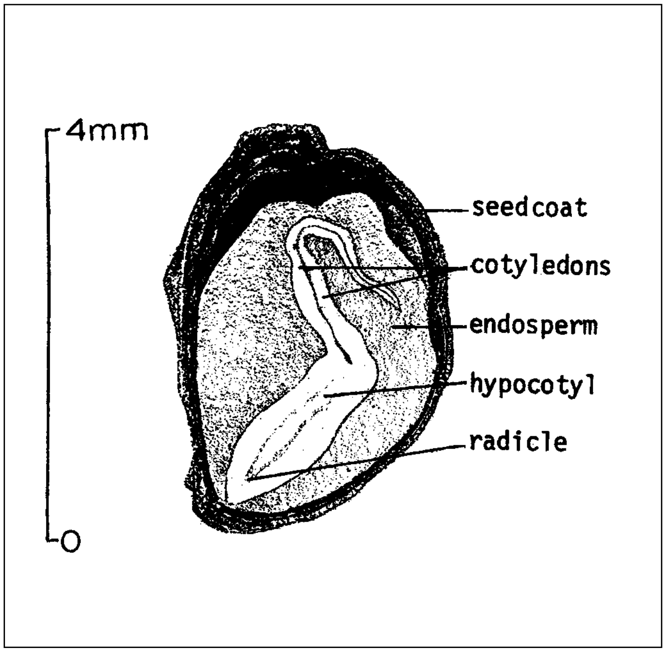


Figure 3—*Tilia americana*, American linden: longitudinal section of a seed.



den persist on the tree, fruit collection is often postponed until after maturity. After a heavy frost, fruits can be shaken from branches onto a canvas tarp and spread out to dry (Brinkman 1974).

Once fruits have been collected, bracts can be removed by flailing or passing the fruits through a de-winging machine. The hard pericarp must then be removed. Fruits of littleleaf and bigleaf lindens have prominent sutures that are helpful in the extraction process by serving as a breaking point for both mechanical and rubbing techniques (Heit 1977). Fruits of European and silver lindens can be handled similarly, and a combination of sieving, screening, and blowing can readily remove debris (Heit 1977). However, fruits of American linden have a hard, tough, leathery pericarp and must be run through a coffee grinder or a similar device or treated with acid to accomplish its removal (Heit 1977). Mechanical extraction of seeds is often difficult. Any crushing force sufficient to fracture the tough pericarp is likely to exert a shattering pressure on the brittle seedcoat (Spaeth 1934). Seed yields and size vary by species (table 3)

Storage. Seeds of the lindens are orthodox in storage behavior and should be stored in sealed containers at a moisture content of 8 to 12%. Seeds of American linden have retained their viability for 2 years when stored under dry conditions at room temperature and for 5 to 6 years when stored at 1 to 4 °C (Heit 1977).

Pregermination treatments. In addition to their tough pericarps, seeds of linden exhibit double dormancy and thus require both scarification and stratification (moist-prechilling) because of their impermeable seedcoat and dormant embryo, respectively. For seeds of littleleaf linden, Heit (1977) recommended a sulfuric acid treatment of 10 to 50 minutes at a temperature ranging from 23 to 27 °C. Colder temperatures required a longer duration of acid treatment. Because all species of linden and individual seedlots within the same species are variable in their percentage and degree of hardseededness, it is advisable to soak some seeds in water for 1 or 2 days to determine the degree of hardseededness before treating with acid. Ten to 20 minutes of acid treatment may be ideal for some seedlots, but 20 to 50 minutes would produce the best results for others. The degree of hardseededness depends on factors such as seed source, time of collection, and storage conditions, including temperature and relative humidity (Heit 1967, 1977). Other scarification treatments include mechanical scarification and hot water treatments, but neither are as good as acid scarification (Heit 1977). Freezing to –80 and –185 °C had little effect on the permeability of the seedcoat (Spaeth 1934). Surface sterilization with sodium hypochlorite (NaOCl) and ethanol proved to control seed pathogens but lowered germination percentages of littleleaf, bigleaf, and silver lindens (Magherini and Nin 1993).

In addition to scarification, stratification is essential for maximum germination and seedling production. Following scarification, seeds must be either fall-sown immediately or stratified at 1 to 3 °C for about 3 months before spring-sowing. Vanstone (1978) recommends stratification in a 1:1 mixture (by volume) of peat and sand containing 30% moisture by weight. Enzyme activity and levels of soluble proteins and amino acids in the seeds increase gradually during stratification at 4 °C (Pitel and others 1989). Nontreated seeds have been known to lie in the ground for over 5 years without germinating while still maintaining viability (Heit 1967). Bigleaf linden requires 3 to 5 months of warm stratification followed by 3 months of cold, and even this treatment does not guarantee high germination (Dirr and Heuser 1987). Flemer (1980) recommends burying seeds in a wooden box filled with damp sand and leaving the box outdoors during the winter. Boxes are then dug up the following fall and the seeds are sown. Seed treatments that consistently result in

Table 3—*Tilia,* linden: seed yield data

	Seed wt/fruit wt		Cleaned seeds/weight (x1,000)				
			Range		Average		
Species	kg/45.4 kg	lb/100 lb	/kg	/lb	/kg	/lb	Samples
T. americana	—	—	—	—	6.6	3	2
	34.1	75	6.6–17.6	3.0–8.0	11	5	15+
	—	—	20–32.1	9.1–14.6	—	—	—
T. cordata	36.3	80	24.9–38.3	11.3–17.4	30.4	13.8	57+
	—	—	48.8–65.1	22.2–29.6	—	—	—
T. x europaea	—	—	23.3–29.7	10.6–13.5	—	—	—
T. platyphyllos	—	—	25.1–30.6	11.4–13.9	—	—	—
T. tomentosa	—	—	20.0–25.1	9.1–11.4	—	—	—

Sources: Brinkman (1974), Heit (1977).

good germination for all species and seedlots have not been developed. Much variability exists among species and seedlots in regards to permeability of the pericarp and seedcoat, as well as stratification requirements.

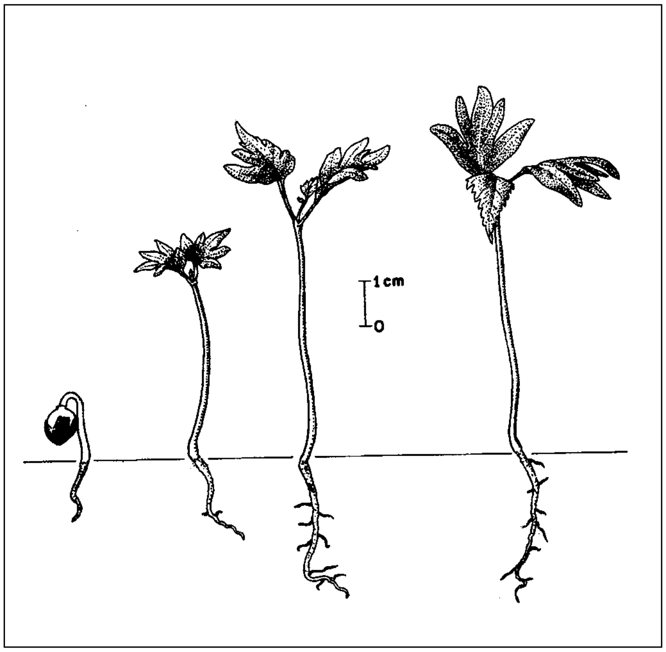
In Europe, dormancy in littleleaf linden is overcome by the use of warm incubation or acid scarification, followed by stratification (Suszka and others 1996). Fully imbibed seeds are first stored for 4 months at 20 to 25 °C (or scarified with concentrated sulfuric acid for 12 minutes), then stratified at 3 °C for 14 to 18 weeks. Stratification should be stopped when the first seeds start to germinate.This complete process may take 8 or 9 months.

Germination tests. Germination is epigeal (figure 4). Optimum germination occurs at temperatures above 20 °C (68 °F), but seeds will germinate at temperatures as low as 2 °C once stratification requirements have been satisfied (Spaeth 1934). Thus, seeds should be checked periodically for radicle emergence during stratification. Light is not required for germination (Heit 1967). The use of any stratification procedure requires far too much time to be used in routine germination testing, however, so rapid estimates of viability are recommended for this purpose. This can be done with tetrazolium staining, indigo-carmine staining, or excised embryo tests (ISTA 1996; Suszka and others 1996). However, these tests require removal of the pericarp and the seedcoat without damaging the embryo. Tetrazolium staining is the most common test. It requires soaking seeds in water for 18 to 24 hours, removing all or a large part of the seedcoat, and soaking the seeds in a 1% tetrazolium solution for 24 to 48 hours at 30 °C.

Pitel and Wang (1988) found that both the rate and percentage of germination of seeds of American linden were increased by treating scarified seeds with a solution of kinetin (1 mg/liter) and gibberellic acid (GA_3, 500 mg/liter. Over 90% germination was obtained after 60 to 80 days at 4 °C. However, GA did not improve germination percentage of seedlots of littleleaf, bigleaf, and silver linden (Magherini and Nin 1993). The conflicting results are likely due to the level of gibberellin present. Natural levels of GA exist in dormant, nonstratified seeds and a sudden increase in the quantity of gibberellin is observed from the sixth week of stratification (Nagy 1980). It is likely that a specific quantity, rather than just the presence of free gibberellins, is required to break dormancy and stimulate germination.

Traditionally, for an accurate germination test, the outer pericarp must be removed and the hard seeds must undergo scarification and stratification. However, excised embryos of American linden that were separated from the seedcoat and endosperm were able to germinate and grow when placed on an agar medium without any pretreatment (Vanstone 1982). If any of the endosperm was retained around the embryo, no growth took place, indicating an apparent lack of embryo dormancy, for the naked embryo will grow when it is separated from other parts of the seed. Some factor that restricts germination seems to be present in the endosperm and must be overcome before an intact seed can germinate. That factor would normally be overcome by stratification. The same result was obtained with bigleaf linden, for germination was induced by removing the endosperm tissue around the radicle (Nagy and Keri 1984).

Figure 4—*Tilia americana*, American linden: seedling development at 1 day and 3, 16, and 19 days after germination.



Nursery practice and seedling care. Most trees in culture are of seedling origin (Kunneman and Albers 1991). However, some are propagated by grafting, chip budding, layering, rooting winter hardwood or leafy softwood cuttings, or tissue culture (Flemer 1980; Howard 1995; Kunneman and Albers 1991). For grafting, seedling rootstocks are used, preferably of the same species as the scion, as incompatibility is a common phenomenon (Kunneman and Albers 1991). Named cultivars are grafted commonly in spring or budded in summer (LHBH 1976). Plants of littleleaf linden have been propagated by somatic embryogenesis initiated from immature zygotic embryos and then established successfully in soil (Chalupa 1990). Except for hybrids such as Crimean and European linden, all can be seed-propagated (Dirr and Heuser 1987).

Production by seed at a specified time is often relatively difficult (Dirr and Heuser 1987; Heit 1967). As described

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previously, seeds show delayed germination because of a tough pericarp, an impermeable seedcoat, and a dormant embryo. Seeds may remain in the ground for several years and never produce a good stand of seedlings. The degree of seedcoat hardness and embryo dormancy varies within and among seedlots for most species (Hartmann and others 2002). Also, germination is irregular, and unknown seed sources and hybridization between species have given rise to variability among seedlings (Kunneman and Albers 1991). In addition, Heit (1977) found that several lots of seeds of bigleaf and silver lindens from Europe contained high percentages of empty seeds, from 20 to 72% (Heit 1977). This condition should always be checked before sowing or treating seeds.

Mature fall-collected seeds may be sown in spring following scarification and stratification (see Pregermination treatments). An alternate method is to collect seeds early, before the pericarp turns brown and sow in the fall. Early seed collections may result in seeds that have soft seedcoats that do not require scarification (Heit 1977). However, some propagators have harvested early and obtained inconsistent results, with the seeds sometimes decaying. Late-harvested seeds may also be germinated the first season but require more treatment than seeds harvested at the ideal stage of maturity (Vanstone 1978).

Seeds are sown in shallow rows—6 to 13 mm ($^1/_4$ to $^1/_2$ in)—in beds and covered with sand to aid in seedling emergence. The emerging seedlings are very delicate and subject to sun scald, so lathe screens or shade netting over the seedbeds greatly improves seedling stands (Flemer 1980). Fall-sown seedbeds should be mulched, protected from rodent damage, and kept moist until germination begins in the spring (Vanstone 1978). Good stands of littleleaf, bigleaf, and silver lindens are normal, but seeds of American linden exhibit great variation in germination from year to year (Flemer 1980). When poor stands result, seedlings should be removed carefully so as not to disturb the bed, for additional germination often occurs the second year after planting. Seedlings are usually outplanted as 1+0 or 2+0 stock.

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Meliaceae—Mahogany family

Toona ciliata Roemer

Australian toon

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Dr. Francis retired from the USDA Forest Service's International Institute of Tropical Forestry

Synonyms. *Toona australis* Harms, *Cedrela toona* var. *australis* (Roxb.) C. DC.

Other common names. toona, Australian redcedar, Burma-cedar.

Growth habit, occurrence, and use. Distributed in a natural range from India to Queensland, Australia (Francis 1951; Webb and others 1984), Australian toon—*Toona ciliata* Roemer—is the only species of *Toona* important in Hawaii and Puerto Rico. It was introduced into Hawaii from coastal rain forest areas of Australia in 1914 (Carlson and Bryan 1959; Streets 1962). Several small plantings of toon of an Indian provenance have reached sawlog size in Puerto Rico. Australian toon is a deciduous timber tree that attains heights of 30 to 43 m. It keeps its leaves longer on moist sites than on drier sites, and sometimes trees are said to be evergreen. Toon has been widely planted because the wood is valued for cabinets, furniture, decorative veneer, boats, and musical instruments (Chudnoff 1984). The red, often highly figured, wood is durable and seasons rapidly (Carlson and Bryan 1959; Francis 1951).

Flowering and fruiting. In Hawaii, Australian toon flowers from April to June. The flowers are bisexual. The 5-valved, teardrop-shaped capsules are 18 to 25 mm long (figures 1 and 2), in pendulous clusters, ripening during July to September. Seeds are disbursed during August to October (Walters 1974). Trees begin to produce seeds as early as 5 years of age, but generally do not do so with regularity or in quantity until they are 10 to 15 years old (Carlson and Bryan 1959).

Collection, extraction, and storage. The capsule turns from green to brown or reddish brown when ripe. When the first capsule in a cluster dehisces, the whole cluster should be picked. Clipping fruited branches using a pruning pole or cherry picker is recommended for seed orchards or open-grown trees. Climbing or felling will be necessary to collect capsules from mature trees in stands. The harvested fruit should be spread on trays in the sun to dry. The light

Figure 1—*Toona ciliata*, Australian toon: seed.

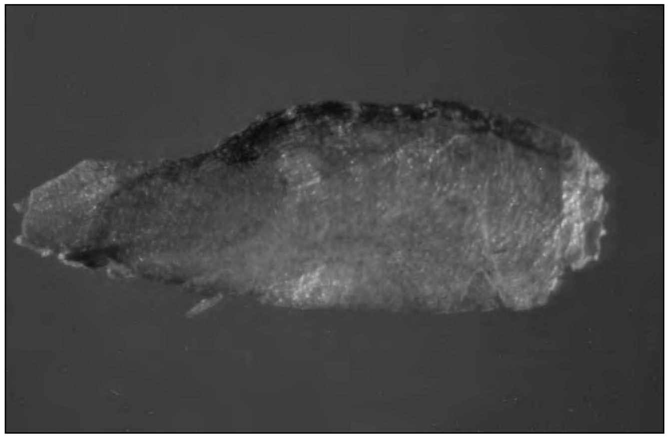
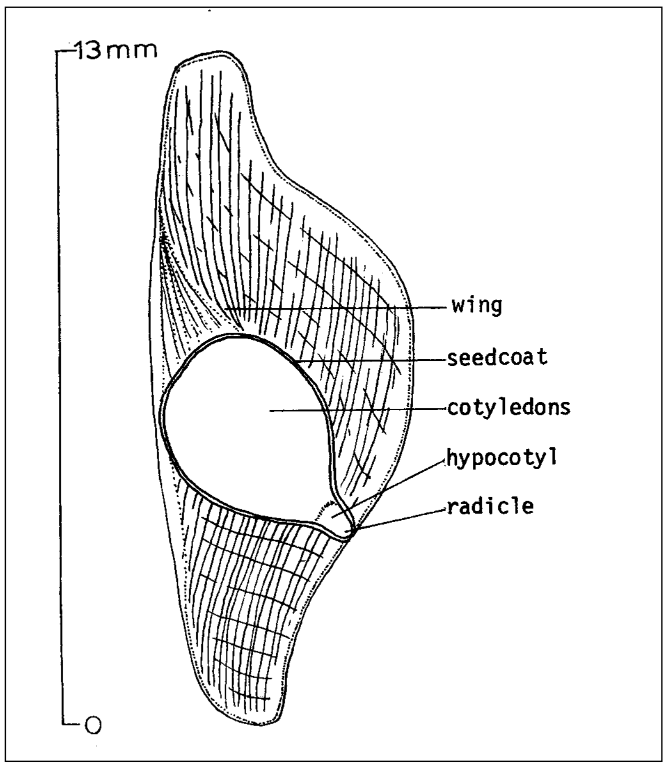


Figure 2—*Toona ciliata*, Australian toon: longitudinal section through a seed with wing attached.



brown, membranous winged seeds (figures 1 and 2) fall from the capsule as the fruit dehisces. Agitation aids the separation of seeds from the fruits. Various seed cleaners can be used to separate the seeds from chaff. Ten samples showed from 293,000 to 375,000 cleaned seeds/kg (133,000 to 174,000/lb) (Walters 1974). Seed purity was about 84% (Walters 1974). Toon seeds can be stored dry in sealed polyethylene bags at about 1 °C (Walters 1974). Even with this apparent orthodox storage behavior, however, storage life is reported to be only from 6 to 12 months (Webb and others 1984).

Germination. Australian toon seeds germinate without special treatment, but stratification for 30 days at 3 °C in plastic bags greatly increases the speed of germination. A water soak also may speed up germination (Walters 1974). Full germination of 90% of unstratified seedlots occurred in 2 weeks; full germination of 96% of stratified seedlots occurred in 1 week (Walters 1974). Another source (Webb and others 1984) cites 40 to 60% germination of fresh seeds. Germination is epigeal.

Nursery practice. Australian toon seeds can be sown in Hawaii and Puerto Rico during any month of the year, but best results in Hawaii are obtained from March to November sowings and in Puerto Rico from April and May sowings. Seeds for bareroot seedling production are broadcast into precut lines. The lines are about 12 mm deep and about 15 cm apart. Most of the seeds that fall away from the lines are put in place as the lines are covered with soil. The beds are made level to prevent washing. The soil is kept moist by frequent watering. No mulch or shade is used. Seedling density in the beds is about 160 to 270 seedlings/m^2 (15 to 25/ft^2). Seedlings are outplanted as 1+0 or $1^1/_2$+0 stock (Walters 1974). Seedlings are now more frequently grown containerized in plastic nursery bags. Seeds are germinated in germination trays or beds and transplanted to the containers after they have developed 2 or 3 leaves. Seedlings can also be planted as striplings or stumps (Webb and others 1984). Australian toon seedlings grow slowly at first and should be given shade for 2 months. Potted stock reaches plantable size in 18 to 24 months (Webb and others 1984). Attacks of the shootborer *Hypsipyla grandella* (Zeller), which usually prohibits planting *Cedrela* species in the Neotropics, are absent or unimportant in toon plantations (Viga 1976; Whitmore and Medina Gaud 1974).

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Taxaceae—Yew family

Torreya Arn.

torreya

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Growth habit, occurrence, and uses. The genus *Torreya* includes 7 species of conifer trees found in North America and eastern Asia (Little 1979; Price 1990). These species of limited distribution represent a genus that in earlier geologic times was widespread in the Northern Hemisphere—Europe, Greenland, Alaska, British Columbia, Oregon, Colorado, Virginia, and North Carolina (Abrams 1955; Boeshore and Gray 1936; Florin 1963; Schwartz and Hermann 1993a). Two species are native in the United States: Florida torreya is endemic to a small area in Florida and Georgia, and California torreya to central California (table 1). Little genetic variability has been found among populations of Florida torreya in contrast to those of California torreya (Schwartz 1993). Although growing in markedly different climates, the 2 species responded similarly in water stress tests (Schwartz and others 1995).

California torreya is a slow-growing, medium-sized tree found along streams and in canyon bottoms and other moist locations (Griffin and Critchfield 1976; Storer and Usinger 1963; Sudworth 1908). In its shrub form, it is found on serpentine soils and in chaparral. In elevation, California torreya ranges from coastal lowlands to almost 2,130 m in the southern Sierra Nevada. Under very favorable conditions, trees may grow to 23 m or more in height and 60 to 90 cm in diameter (Sudworth 1908). The tallest tree now on record is 29.3 m tall and 638 cm in circumference at 137 cm above ground (AFA 2000).

Florida torreya, also a slow-growing tree, is an endangered species found only at low elevations on ravine slopes 12 to 45 m above constant running streams on the east bank of the Apalachicola River and tributaries in Florida and Georgia and in a colony on low flat land that is 10 km west of the river (Kurz 1938; Nicholson 1990; Schwartz and Hermann 1993a&b). Florida torreya is commonly associated with seepage locations on soils ranging from coarse or fine sand to clay with limestone pebbles (Kurz 1938; USFWS 1986). In their native habitat, mature trees have reached 15 to 20 m in height and 30 to 60 cm in diameter (Harrar and Harrar 1962; Nicholson 1990; Schwartz and others 1995). However, due to severe population decline since the 1950s (the primary cause of this decline is unknown), the 1,500 or fewer immature survivors are generally less than 2 m tall (Bronaugh 1996; Schwartz and Herman 1999; Schwartz and others 1995). The tallest existing trees are found in several plantings outside of the species' endemic habitat; the largest, in North Carolina, measures 13.7 m tall and 277 cm in circumference (AFA 2000).

Because of their low availability, uses of both species of torreya are limited. Their wood is aromatic, rot-resistant, fine-grained, and excellent for cabinet-making (Burke 1975;

Table 1—*Torreya*, torreya: nomenclature and occurrence

Scientific name & synonym(s)	Common name(s)	Occurrence
***T. californica* Torr.** *T. myristica* Hook. *Tumion californicum* (Torr.) Greene	**California torreya,** California-nutmeg, stinking-yew, stinking-cedar	Central California—scattered in the Coast Ranges and on western slopes of the Cascades & Sierra Nevada
***T. taxifolia* Arn.** *Tumion taxifolium* (Arn.) Greene	**Florida torreya,** Florida-nutmeg, stinking-cedar	E bank of Apalachicola River & tributaries from Decatur Co., Georgia, to Liberty Co., Florida, & an outlying population in Jackson Co., Florida

Sources: Griffin and Critchfield (1976), Kurz (1938), Little (1979), Stalter (1990), Sudworth (1908).

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Peattie 1953). Both species were used locally for such purposes as shingles, fence posts, and firewood. They grow satisfactorily outside of their native range and have received moderate use as ornamentals (Burke 1975; Sargent 1875; Wilson 1938). Fruits of California torreya were collected for food by native Californians, and the characteristics of its oil compare favorably with those of pine-nut oil for cooking purposes (Burke 1975). Squirrels have been observed eating fruits and seeds of Florida torreya and antler-rubbing scars provide evidence of use by deer (Bronaugh 1996; Nicholson 1990; Schwartz and Hermann 1993a).

Flowering and fruiting. Torreyas are dioecious. The male flowers are small, budlike, and clustered on the under sides of twigs in axils of leaves produced the previous year (Abrams 1955; Jepson 1925; Sargent 1933; Sudworth 1908). The female flowers are less numerous and occur on the lower sides of the current year's twigs. After fertilization, they develop singly into sessile, thin-fleshed arils that mature during the second season as green to purplish drupes 25 to 44 mm long (figure 1). When mature, the leathery cover eventually releases a 25- to 30-mm yellow-brown seed (Munz and Keck 1959) (figure 2). The thick woody inner seedcoat is irregularly folded into the female gametophyte, and the embryo is minute (figure 3).

Both species flower in March and April, with some flowers of Florida torreya appearing as early as January and some of California torreya extending into May (Rehder 1940; Sargent 1933; Stalter 1990; Weidner 1996). Under favorable growing conditions, Florida torreya produces male and female flowers about age 20 (Stalter 1990); in greenhouse conditions, 5-year-old sprouts produced pollen (Schwartz 1996).

Figure 1—*Torreya taxifolia*, Florida torreya: the fruit is sessile and drupe-like.

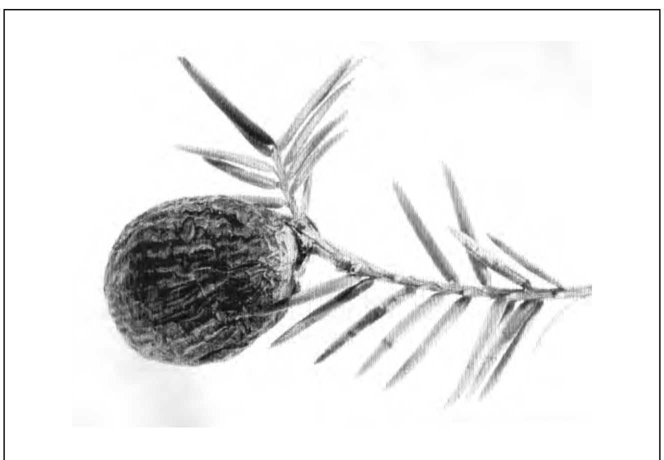


Figure 2—*Torreya*, torreya: large seeds of *T. californica*, California torreya (**left**) and *T. taxifolia*, Florida torreya (**right**).

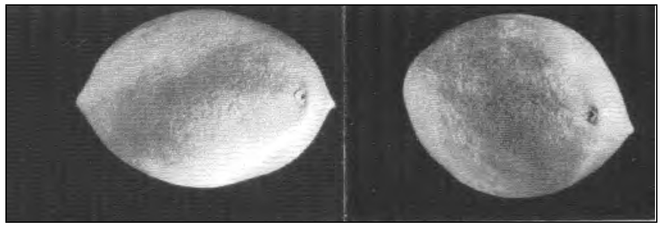
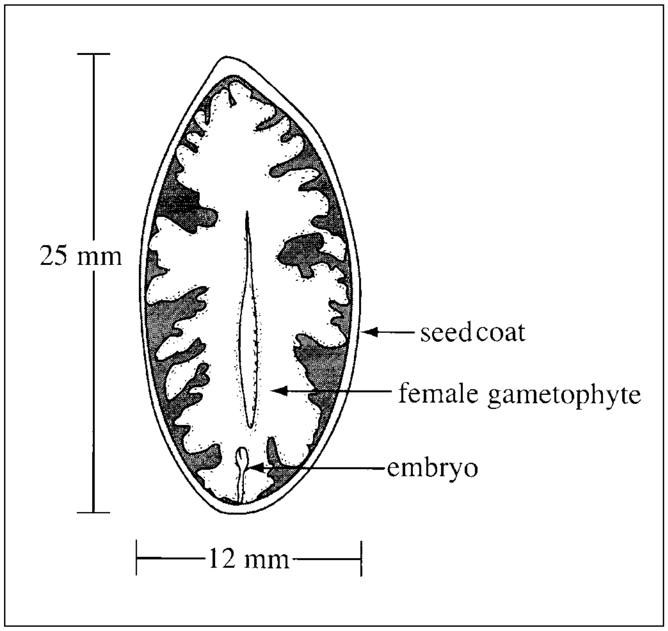


Figure 3—*Torreya californica*, California torreya: longitudinal section through a seed showing the folds of the inner seedcoat extending into the endosperm.



Information on the fruit production characteristics of both torreya species is sparse and inadequate. Fruits mature from August till November (Mirov and Kraebel 1939; Rehder 1940; Stalter 1990). At the Alfred B. Maclay Gardens in Tallahassee, Florida, fruit production from 8 trees was low and varied by tree and year. No fruits were produced in 4 years, and more than 100 fruits were available in 1985, 1986, 1987, and 1989 (Weidner 1996).

Collection, extraction and storage. Collection of Florida torreya fruits from the endemic population is not possible now because there are only scattered sexually mature male trees and no mature females (Bronaugh 1996; Schwartz and Hermann 1993a; Schwartz 1996). Trees in cultivation include less than 2 dozen reproductive females (Bronaugh 1996), so extraordinary diligence is required to collect any seeds that are produced. Fruits have been picked slightly green to gather them before the squirrels do and then held in open storage until the outer cover turned dark; then the pulp was softened in water and removed by rubbing fruits against hardware cloth (Weidner 1996).

Fruit production of California torreya is common and widespread enough to forestall concerns about shortage; several hundred pounds may be collected in single commercial collections (Callahan 1996). The fruits are generally picked from the trees but are sometimes collected after they have been shed. Seed extraction is about the same as for Florida torreya, with the softened pulp removed by water pressure and some hand rubbing (Callahan 1996). Care is needed to avoid damage to the relatively tender seedcoat. Seed quality of California torreya is generally good and can be improved sometimes by separating light seeds through flotation.

Storage experience is short-term and fragmentary because torreya seeds are generally used as available. Based on incidental observations, the seeds may be recalcitrant, as high moisture content appears necessary to maintain their viability. California torreya has been stored in moist vermiculite or sphagnum moss at 2 to 7 °C for up to 3 years (Callahan 1996). Some seeds of both species will germinate in lengthy cool or warm stratification (Callahan 1996; Weidner 1996).

Seeds of California torreya averaged 324/kg (147/lb), with a range of 243 to 421/kg (110 to 191/lb) in 3 samples (Roy 1974). Florida torreya had 496 seeds/kg (225/lb) in 1 sample at a moisture content of 8.6% (Roy 1974).

Pregermination treatments and germination tests. Standard germination test procedures have not been developed yet for torreya seeds. Both species require lengthy after-ripening and stratification, but efforts made to date have not identified methods for timely germination testing of fresh or stored seeds.

As available, fresh seeds of Florida torreya have been tested at Alfred B. Maclay State Gardens according to the 9 variations of methodology specified in the recovery plan for the species (USFWS 1986). Warm stratification in a half and half mixture of Canadian peat and coarse sand for 6 months in a greenhouse at 13 to 18 °C has produced the best results. Gentle cracking of the distal end of the seedcoat before warm stratification produced somewhat higher germination than a preliminary 20-minute soak in 10% chlorine bleach or stratification alone (table 2) (Weidner 1996).

Germination averaged lowest for sowings made directly into outdoor beds. The germination results indicate that seedcrop quality or other factors differed from year to year, and results were also not very consistent for the same pretreatment and germination sequence.

Procedures have been prescribed for determining viability of torreya seeds quickly by a tetrazolium (TZ) test on excised embryos (Moore 1985). Seed preparation involves puncturing the seedcoat, soaking the seeds in water for 18 hours, and then cutting them open to expose nutritive tissue and the distal end of the embryo. The prepared seeds are soaked in a 1% TZ solution for 24 to 48 hours, depending on temperature; nutritive tissue and embryo are then further exposed and evaluated. Viable seeds have a completely stained embryo and nutritive tissue.

Nursery practices. Torreya germination is hypogeal. Both California and Florida torreyas can be reproduced from seeds but quantities grown are so small and infrequent that nursery practices are underdeveloped.

The protocols specified in the recovery plan (USFWS 1986) and the germination resulting therefrom (table 2) are evidently the most recent, systematic, and successful attempts to produce Florida torreya seedlings for outplanting. Seedlings are slow growing and very susceptible to damping-off, so repeated fungicide drenches are necessary.

Seeds of California torreya sown untreated in the fall will germinate late the next summer or in the second spring. Germination can be obtained by April of the first season by sowing in the fall and keeping the seedbed at 7 to 10 °C (Callahan 1996). Seeds generally have high viability—90 to

Table 2—*Torreya,* torreya: germination of *T. taxifolia* seeds

Pre-germination treatment*	Germination by seed year 1985	1990	1993	Average
6 months of warm stratification	69	13	80	54.0
Bleach + 6 months of warm stratification	77	0	85	54.0
Cracking + 6 months of warm stratification	100	25	86	70.3
3 mon of warm, then 3 months of cold stratification	85	38	58	60.3
Bleach + 3 months of warm, then 3 months of cold stratification	77	25	44	48.7
Cracking + 3 months of warm, then 3 months of cold stratification	62	38	35	45.0

Source: Weidner (1996).

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98% germination. In a test of seeds stratified for 3 months, 92% germinated in 232 days after sowing (Mirov and Kraebel 1939). Two growing seasons are required to produce seedlings 15 to 25 cm tall (Callahan 1996; Wilson 1996).

Both species sprout from stumps or root crowns and can be propagated vegetatively. Metcalf (1959) described sprouting of California torreya as vigorous—"like redwood." Stalter (1990), Godfrey (1988), and others indicated that the current endemic Florida torreya population probably originated largely from vegetative propagation, but Schwartz and Hermann (1993a) concluded that most originated from seeds.

The urgency of conserving Florida torreya has stimulated development of its reproduction by cuttings (Bailo and others 1998; Nicholson 1988, 1993). Up to 91% of cuttings collected in November from trees throughout the species' native range rooted in a mixture of pumice, peat, and perlite mixture. The cuttings were potted and grown for 2 years and then shipped to botanic gardens and research institutions. A database on living Florida torreya material is maintained by The Center for Plant Conservation, headquartered at the Missouri Botanical Garden, St. Louis, Missouri.

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Euphorbiaceae—Spurge family

Triadica sebiferum (L.) Small

tallowtree

Franklin T. Bonner

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Synonym. *Sapium sebifera* (L.) Roxb.

Other common name. Chinese tallowtree.

Growth habit, occurrence, and use. Tallowtree—*Triadica sebiferum* (L.) Small—is a small deciduous tree that attains heights of about 10 m at maturity. A native of China, the species has been widely planted in the coastal plain from South Carolina and Florida to Texas, Oklahoma, and Arkansas. The bright red fall foliage makes the tree a popular ornamental, and the seeds have some value as wildlife food. In Asia, oils are extracted from the seeds and waxes from the seedcoats for use in a wide variety of products, including diesel fuel additives, soaps, candles, and cloth dressings (Bringi 1988; Samson and others 1985; Singh and others 1993; Vines 1960). Tallowtree readily escapes from cultivation and is common along roadsides of the Gulf Coast, where many consider it a pest species.

Flowering and fruiting. Both pistillate and staminate flowers are borne on the same yellowish green spike in the spring. The fruit, ripening in October to November, is a rounded, 3-lobed capsule, 8 to 13 mm in diameter (Vines 1960). Its greenish color changes to a brownish purple at maturity (Bonner 1974). There are 1 to 3 white waxy seeds per capsule (figures 1 and 2). In India, this species bears fruit as early as the third year after planting, and mature trees can yield 20 to 25 kg (Singh and others 1993).

Collection, cleaning, and storage of seeds. The dry capsules can be collected from the trees by hand after dehiscence (fruit-splitting) has started. Seeds can be removed from the capsules by gentle flailing in burlap bags or by being run through macerators at slow speeds. On a sample of capsules from a tree in central Mississippi, the following data were obtained (Bonner 1974):

Capsules per volume	30,300/hl (10,700/bu)
Seeds per weight	6,100/kg (2,780/lb)
Moisture content of seeds (% of fresh weight)	6
Sound seeds (% of total seeds)	90

Figure 1—*Triadica sebiferum*, tallowtree: seed.

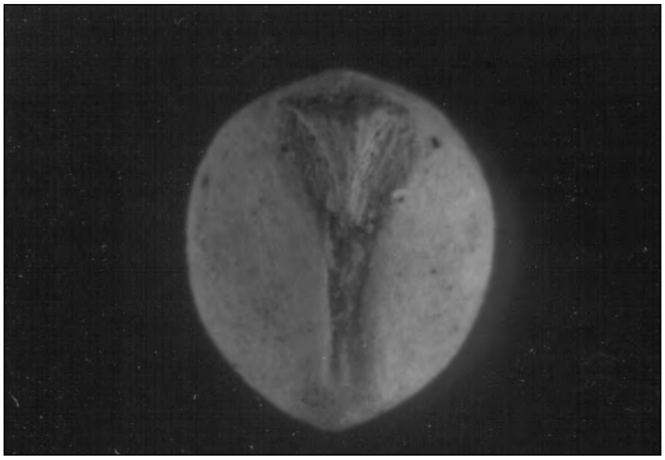
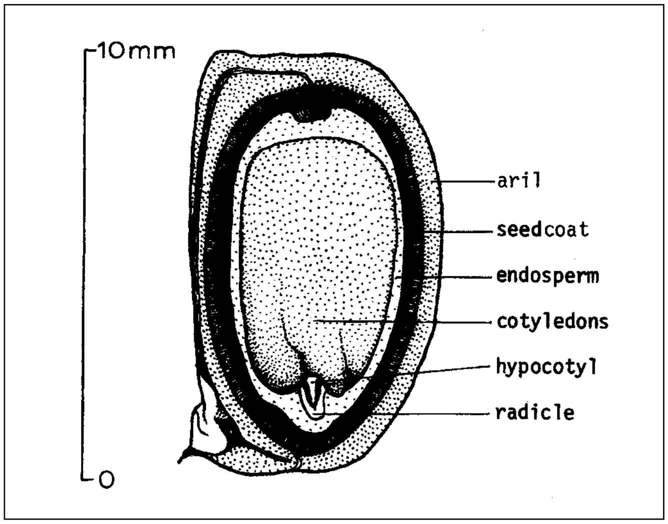


Figure 2—*Triadica sebiferum,* tallowtree: longitudinal section through a seed.



There are no known storage tests with seeds of tallow tree, but drying the sample noted above to 6% without killing the seeds indicates that they are orthodox in storage behavior. Short-term storage at low temperatures and seed moisture contents should be no problem. The seeds have a lipid content of about 20% (Zubair and others 1978), however, so sub-freezing temperatures should be used for any storage over 5 years.

Germination tests. Seeds of tallowtree are not dormant and do not typically require pretreatment. Germination results of 60 to 62% in germination beds have been reported from India (Singh and others 1993). Fresh seeds from the Mississippi collection had a laboratory germination of 38% after 30 days on moist Kimpak at day-night temperatures of 30 and 20 °C. The seeds received 8 hours of light during the day temperature. Moist stratification at 2 °C for 34 days increased the rate of germination but did not boost the percentage. Sixty days of stratification apparently induced a deep secondary dormancy (Bonner 1974). Tallowtree can also be propagated by cuttings from root suckers (Singh and others 1993).

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Pinaceae—Pine family

Tsuga Carr.

hemlock

Jill R. Barbour, Robert H. Ruth, and Robert P. Karrfalt

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Growth habit, occurrence, and use. Trees of the hemlock genus—*Tsuga* spp.—are tall, straight, late successional climax evergreens with conical crowns and slender, horizontal to pendulous branches. Fourteen species have been reported; 4 of these are native to the United States and the others to the Himalayas, China, Taiwan, and Japan. The name *tsuga* is a Japanese word meaning "tree-mother" (Dirr 1998). Native American names for the North Country (that is, Canada), *hoe-nadia,* and for the lands of upper New York, *oh-neh-tah,* both mean "land of the hemlock" (Dirr 1998).

Of the 4 native species in the United States (table 1), both eastern and western hemlocks are used commercially for lumber and pulpwood. The bark of eastern hemlock has been a source of tannin for the leather industry. In central and southern Oregon and some other areas, mountain hemlock has become an important part of the softwood sawtimber volume.

Much of eastern hemlock has been severely affected by the hemlock woolly adelgid—*Adelges tsugae* Annand—in New England and the mid–Atlantic region (Dirr 1998). The hemlock woolly adelgid has also been noted on Carolina hemlock in the Tallulah Gorge in northeastern Georgia (Price 2002). Although the hemlock woolly adelgid occurs on mountain and western hemlocks from southern California to southeastern Alaska, these 2 species are resistant to the insect (McClure and others 2001).

Carolina hemlock overlaps the southern range of eastern hemlock, but it is a smaller tree with longer needles and cones. The wood serves the same uses as eastern hemlock, but the species is not abundant and of only minor commercial importance. Carolina hemlock is especially suitable for ornamental plantings.

Mountain hemlock is important mainly for watershed protection and the scenic beauty it adds to subalpine environments of Pacific Northwest mountain ranges. Its populations are disjunct due to the physical separation of its high-elevation sites. Due to the disjunct nature of its distribution, mountain hemlock was included in a world list of threatened species (Farjon and others 1993). It varies in size from a sprawling shrub at the timberline to a medium-sized forest tree.

Geographic races. Eastern, western, and mountain hemlocks have long north–south ranges and grow in a variety of habitats. Through natural selection, they apparently have developed numerous genetic types, each adapted to its local habitat.

Table 1—*Tsuga*, hemlock: nomenclature and occurrence

Scientific name	Common name(s)	Occurrence
T. canadensis **(L.) Carr.**	**eastern hemlock,** Canada hemlock, hemlock	Nova Scotia to S Ontario, S to N Georgia & Alabama
T. caroliniana **Engelm.**	**Carolina hemlock**	Mountains of Virginia to South Carolina to Georgia & Tennessee
T. heterophylla **(Raf.) Sarg.**	**western hemlock,** Pacific hemlock, hemlock	Pacific Coast from Alaska to Washington, Oregon, & California & in mtns of N Idaho & NW Montana
T. mertensiana **(Bong.) Carr.**	**mountain hemlock,** black hemlock	Pacific Coast regions from Cook Inlet, Alaska, to central California & to W Montana

Source: Ruth (1974)

A series of experiments with eastern hemlock (Baldwin 1930; Nienstaedt 1958; Olson and others 1959; Stearns and Olson 1958) showed that seedlings grown from southern seed sources tend to harden-off and go dormant later in the autumn and make more total growth (and the seeds requires less stratification) than those from northern sources. Southern seeds germinate best when temperatures approach 21 °C, whereas northern seeds do best near 13 °C. Seedlings from southern sources planted in Wisconsin grew late into the fall and were damaged more severely by frost than were their northern counterparts.

Similar results were obtained with western hemlock from 18 western provenances planted at various sites in Great Britain. Western hemlock seedlings from southern parts of this species' native range grew faster and set terminal buds later in the season than those from the North. However, when planted in northern Great Britain, they suffered severe damage from frost and cold winds. Frost damage was reduced if seedlings were planted under a high forest cover (Lines and Aldhous 1962, 1963; Lines and Mitchell 1969). Seed weight was found to decrease significantly from south to north, with collections from Alaska expected to have at least 110,000 more seeds/kg (50,000/lb) than western hemlock seeds from Oregon (Buszewicz and Holmes 1961). Kuser and Ching (1981) found significant differences among provenances in 100-seed weights, but there were only low correlations of seed weight with latitude, elevation, or distance from the Pacific Ocean. An increase in elevation on Vancouver Island, British Columbia, tended to increase germination rate and total germination (Edwards 1973).

Provenances of western hemlock with the fastest growing seedlings are from the southern part of the range; those with the slowest growing seedlings are from the northern part of the range as well as from the upper elevational extremes in the Rocky Mountains (Kuser and Ching 1981). In the case of western hemlock, the tree seed zones delineated by the Western Forest Tree Seed Council (WFTSC 1966b) may be used in Oregon and Washington. Those developed by the Organization for Economic Cooperation and Development (Piesch and Phelps 1970) may be used in British Columbia. A seed transfer zone map has been published for Oregon (Randall 1996).

Jeffrey hemlock—*Tsuga* × *jeffreyi* (Henry) Henry—has been reported as a cultivated hybrid of western and mountain hemlocks (Little 1979; Means 1990; Rehder 1949). Some French taxonomists proposed that mountain hemlock itself is an intergeneric hybrid of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock and they renamed it *Tsuga–Picea hookeriana* (Campo-Duplan and Gaussen 1948; Vabre-Durrieu 1954a&b). They considered a California form of mountain hemlock known as *Tsuga crassifolia* Flous to be a cross of mountain hemlock and Engelmann spruce (*Picea engelmannii* Parry ex Engelm). These hypotheses were rejected by American foresters, largely because of the absence of backcrosses and hybrid swarms in the field (Duffield 1950; Means 1990).

Many horticultural varieties of hemlock, including compact, weeping, spreading, and columnar forms, have been described (Dallimore and Jackson 1957; den Ouden and Boom 1965; Rehder 1940, 1949; Swartley 1945). They are widely planted as ornamentals throughout the temperate parts of the Northern Hemisphere.

Flowering and fruiting. Hemlocks are monoecious plants. Male and female strobili develop in clusters near the ends of lateral branches; each one consists of a central axis with spirally arranged microsporophylls. The male sporangia open transversely and the pollen is simple (Radford and others 1968). In mountain hemlock, pollen release is both protogynous and synchronous with female receptivity (Means 1990). The pollen is extremely sensitive to drying, which can prevent seed development in eastern hemlock (Godman and Lancaster 1990).

Ovulate strobili are erect, with nearly orbicular scales (each scale has 2 basal ovules), subtended by a membranous bract about the same length as the scale; they occur terminally on the lateral shoots of the previous year. In western hemlock, the total number of ovuliferous scales per cone is about 23 and about 70% of the scales are fertile (Colangeli and Owens 1989a). High temperatures in July the year before cone production favor flower initiation in mountain hemlock (Means 1990).

Hemlock is the only genus of the Pine family in which the mechanism of pollination involves nonmicropylar germination. Because of this difference, western hemlock seed cones are receptive for a much longer period than those of other conifers. Cones are receptive from shortly after bud burst until cone closure. The average number of days between bud burst and cone closure for western hemlock was 34 days in 1983 and 23 days in 1984 (Colangeli and Owens 1989a). Maximum pollination and seed efficiency (filled seed divided by the potential number of seeds per cone) is obtained when 50 to 75% of the cones have emerged beyond the cone scales (Bramlett and others 1977; Colangeli and Owens 1989a).

Hemlock pollen does not enter the cone micropyle but attaches to the waxy layer of the exposed portion of the bracts and ovuliferous scales. The bracts of western hemlock can trap more than 100 pollen grains, the average pollen grain count per bract from controlled pollinations being 34, with a range from 2 to 116 (Colangeli and Owens 1989a). The ovuliferous scales elongate over the bracts, trapping the pollen between the bracts and scales. About 4 to 7 days after pollen germination, the pollen tubes grow into the micropyles; usually 1 to 6 pollen tubes and sometimes up to 10 pollen tubes have been found in each micropyle (Colangeli and Owens 1989a). In western hemlock, pollen is not essential for seed cone enlargement and unpollinated ovules can continue seedcoat development, but the seed will not have an embryo or gametophytic tissue (Colangeli and Owens 1990a).

Cones mature in 1 season and are small, pendant, globose to ovoid or oblong, with scales longer than the bracts (figure 1). Carolina hemlock has the largest seeds of the native hemlocks, followed by mountain hemlock and eastern hemlock, with western hemlock having the smallest seeds (table 2; figure 2). Eastern hemlock has the smallest cones; they measure 1.5 to 2.5 cm by 1 to 1.5 cm. Eastern hemlock trees grown from eastern and southern sources have larger cones than do those grown from northern and western sources (Godman and Lancaster 1990). Western hemlock cones measure 1 to 3.0 cm by 1to 2.5 cm; Carolina hemlock cones measure 2.5 to 4 cm by 1.5 to 2.5 cm. Mountain hemlock have the largest cones, which measure 3 to 6 cm by 1.5 to 3 cm (FNAEC 1993; Harlow and Harrar 1968; Hough 1947; Sargent 1933).

Cone production of hemlock usually begins when trees are 20 to 30 years of age, a little later if trees are shaded. All 4 species of hemlock bear some cones almost every year and large crops are frequent (table 3). Cones often remain on the hemlocks well into the second year, being especially conspicuous on the tops of mountain hemlock. Wisconsin had good eastern hemlock cone crops on 61% of the 32 years recorded (Godman and Lancaster 1990). Eastern hemlock trees as old as 450 years have been seen bearing cones. Western hemlock bear cones every year with heavy crops every 3 to 4 years; in Alaska good crops occur every 5 to 8 years (Packee 1990). In Washington and Oregon, mountain hemlock trees 175 to 250 years old bear medium to heavy cone crops at 3-year intervals (Means 1990). Despite the frequency of cone crops, seed viability in hemlocks is generally low. Less than half the seeds in a cone are viable (Burns and Honkala 1990).

The period of dissemination of western hemlock seeds (table 4) can extend over a full year but the seeds are only viable during their first growing season (Packee 1990; Harris 1969). Most western hemlock seeds fall within 610 m from the tree, whereas eastern hemlock seeds fall within tree height due to their small wings (Godman and Lancaster 1990). Seeds remaining in cones are usually sterile in eastern hemlock.

Figure 1—*Tsuga*, hemlock: cones of *T. canadensis*, eastern hemlock (**upper left**); *T. mertensiana*, mountain hemlock (**lower left**); *T. carolina*, Carolina hemlock (**center**); and *T. heterophylla*, western hemlock (**right**).

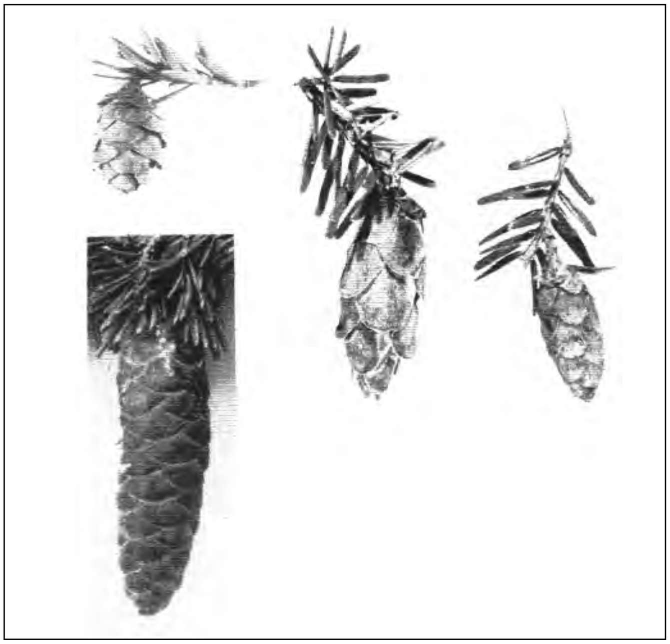


Table 2—*Tsuga*, hemlock: seed yield data

Species	Seeds (x1,000)/weight Range /kg	Range /lb	Average /kg	Average /lb	Samples
T. canadensis	273–794	124–360	412	187	69
T. caroliniana	167–213	76–97	—	—	2+
T. heterophylla	417–1,120	189–508	573	260	106
T. mertensiana	132–459	60–208	251	114	6

Sources: Burns and Honkala (1990); Buszewicz and Holmes (1961), Hill (1969), Rafn (1915), Toumey and Korstian (1952), Toumey and Stevens (1928), Ruth (1974).

Table 3—*Tsuga*, hemlock: height, seed-bearing age, seedcrop frequency, and cone ripeness criteria

Species	Height at maturity (m)	Year first cultivated	Minimum seed-bearing age (yr)	Years between large seed-crops	Cone ripeness criteria	
					Pre-ripe color	Ripe color
T. canadensis	18–30	1736	20–30	2–3	Yellow-green	Purple-brown
				15	Green	Tan to brown
T. caroliniana	12–21	1881	—	—	Purple	Light brown
T. heterophylla	18–75	1851	20–30	5–8	Green with purple tips	Brown with red-brown tips
T. mertensiana	7.5–45	1854	20–30	1–5	Yellow-green to brown	Brown

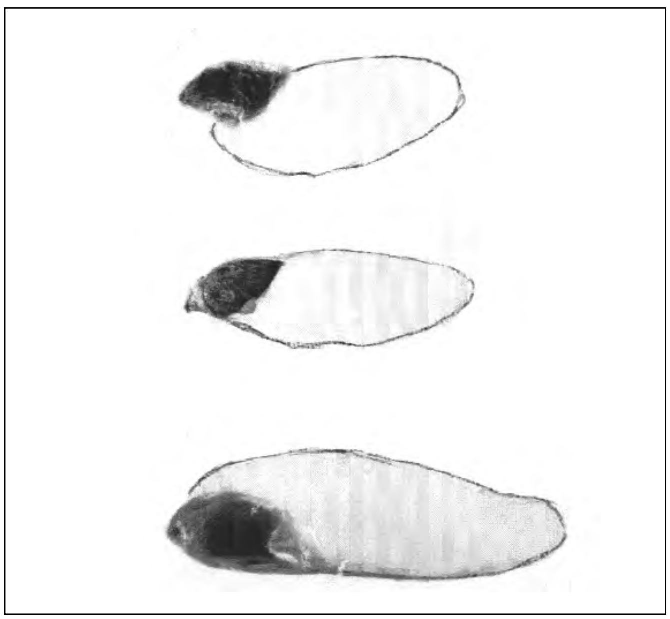
Sources: Burns and Honkala (1990), den Ouden and Boom (1965), Franklin (1968), Frothingham (1915), Harlow and Harrar (1968), Harris (1969), Hough (1947), Merrill and Hawley (1924), Olson and others (1959), Ruth (1974), Ruth and Berntsen (1955), Sudworth (1908).

Table 4—*Tsuga,* hemlock: phenology of flowering and fruiting

Species	Location	Flowering	Fruit ripening	Seed dispersal
T. canadensis	Southern range to northern range	Apr–early June	Sept–Oct	Sept–winter
T. caroliniana	North Carolina to South Carolina	Mar–Apr	Aug–Sept	—
T. heterophylla	Oregon to Washington	Apr–May	Sept–Oct	Oct–May
	S British Columbia	—	Sept 15	Oct–June
	SE Alaska	Late May-June	Sept–Oct	Oct
	W central Oregon	Mid to late Apr	—	Sept–May
	Idaho	May 27–June 5	Aug	Sept 17–winter
T. mertensiana	Oregon	June	Late Sept–Oct	—
	British Columbia, Alaska	June–mid-July	Late Sept-Nov	—
	Bitterroot Mtns, Idaho	Aug	—	—

Sources: Allen (1957), Burns and Honkala (1990); Ebell and Schmidt (1963), Frothingham (1915), Garman (1951), Gashwiler (1969), Godman (1953), Green (1939), Harris (1967), Harris (1969), Heusser (1954), Hough (1947), James (1959), Leiberg (1900), Radford and others (1964), Ruth (1974), Ruth and Berntsen (1955).

Figure 2—*Tsuga*, hemlock: seeds of *T. canadensis*, eastern hemlock (**top**); *T. heterophylla*, western hemlock (**center**); and *T. carolina*, Carolina hemlock (**bottom**).

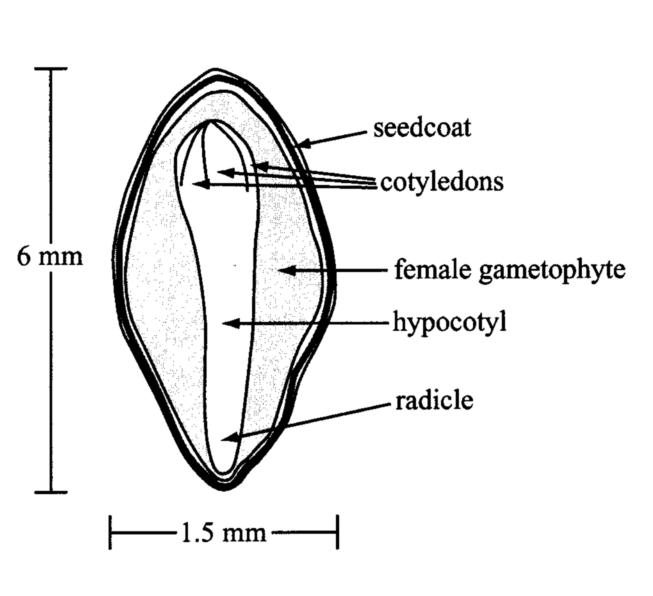


Western hemlock generally produces less than 40 seeds per cone; usually less than 20 of these are filled (Edwards 1976). At a clone bank in Victoria, British Columbia, the average number of seeds per cone was 34, and 22 seeds were filled when counted in 1983 and 1986 (Colangeli and Owens 1990b). The number of filled seeds counted on the exposed cut-face of a cone is a good predictor of total filled seeds per cone (Meagher 1996). The number of cones needed to estimate total filled seeds within ± 5 seeds ranged from 3 to 60 cones (Meagher 1996).

Prepollination ovule abortion produces small, flat seeds. Colangeli and Owens (1990b) found that it accounted for an average of 11 and 14% reduction in filled-seed yield in 1983 and 1986, respectively. Postpollination ovule abortion occurred in about 4% of the ovules, corresponding to less than 1 seed per cone (Colangeli and Owens 1990b). Insufficient pollination—which is usually the reason for low seed set—resulted in 25% empty seeds in 1983 and 66% empty seeds in 1986 (Colangeli and Owens 1990b).

Embryos have 3 to 6 cotyledons (figure 3) (Sargent 1933). Kuser and Ching (1981) found provenance variation

Figure 3—*Tsuga mertensiana*, mountain hemlock: longitudinal section through a seed.



in cotyledon number in western hemlock. Seedlots from the Rocky Mountains produced higher frequencies (15%) of 4-cotyledon seedlings than those from the Cascade Mountains or coastal zones (11%). The embryo extends the full length of the seed. Olson and others (1959) reported that embryos from eastern hemlock are about 3 mm long and 0.5 to 0.7 mm in diameter.

Collection of fruits. Hemlock cones are small and, therefore, more difficult to harvest than the larger cones of many conifers. They are most easily collected from tops of trees felled during harvest cuttings, but it is important that seeds from such collections are checked for maturity. Usually cone collection is delayed until shortly before seed dispersal to ensure full maturity of the seeds. Cones also can be harvested by the use of ladders, pole pruners, and various kinds of climbing equipment.

Based on a study of western hemlock in southern British Columbia, Allen (1958) recommended September 15th as a suitable date to begin cone collection even though cones are still green and hard. Seeds collected earlier (August 30th) had lower total germination. The germination rate of seeds collected September 15th was improved by storage and stratification. Seeds of western hemlock cones that are stored for 3 to 6 months before seed extraction had higher percentages of germinating seeds (91%) than did seeds from cones stored for 1 month before extraction (75%) (Leadem 1980). Also working with western hemlock, Harris (1969) found a few seeds viable when extracted as much as 70 days before seed dispersal. When cones were left on the tree, the percentage viability increased gradually until almost dispersal time.

Extraction and storage of seeds. Handling procedures for hemlock cones and seeds follow those of other conifers. Usually cones are stored—often for several weeks and sometimes months—in permeable sacks in open-sided cone drying sheds while awaiting processing. This covered storage serves as a preliminary curing process. Green cones tend to mold during storage, especially if stored without surface drying. Adequate air circulation is needed around each sack to minimize heating and mold buildup. Under proper conditions, western hemlock seeds may remain in the cones up to 6 months without detrimental effects upon seed quality. Leadem (1980) found that seeds from cones refrigerated at 2 °C had no better quality than seeds from cones stored outdoors.

An additional, or sometimes alternate, procedure is to place cones in a heated room for up to 36 hours before actually placing them in a drying kiln. This avoids exposing seeds that are nearly saturated with water to high kiln temperatures, a procedure that damages some conifer seeds. It also reduces kiln time and cost.

There are few problems in extracting seeds from hemlock cones. According to Baldwin (1930), mature hemlock cones need little artificial heat to open. Kiln-drying temperatures range from 31 to 43 °C, with drying time about 48 hours (Deffenbacher 1969; Isaacson 1969; Ruth 1974; Ward 1969). In the West, few hemlock cones are processed, and kiln schedules generally follow those for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and pine (*Pinus* spp.).

Eastern hemlock cones that are picked green, and thus are difficult to open, usually can be opened by exposure to repeated cycles of moistening followed by drying at 38 °C. Eastern hemlock cones collected just as they turn tan will open readily upon drying (Olson and others 1959). Mold-infested cones often open poorly, making seed extraction difficult. Seeds are extracted by tumbling or shaking the cones during or immediately after kiln-drying. On the tree, western hemlock cones open and close readily in response to changing moisture conditions and require many flexings of the cone scales before all seeds are dislodged; with kiln-drying and tumbling or shaking, a single opening of the cone scales appears sufficient for good seed extraction (Harris 1969).

Seeds are nearly surrounded by their wings (figure 2). Unlike the seeds of fir, Douglas-fir, and some pines, hemlock seeds have an entire wing that can be detached without serious damage to the seeds themselves (AOSA 2001).

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Seeds are de-winged, and wing parts and foreign matter removed in a fanning mill or gravity separator. Minimum standards of 90% purity and 60% viability have been established for seedlots of western hemlock (WFTSC 1966a). The low viability often reported for eastern hemlock may be due to the difficulty of separating out low-quality seeds (Olson and others 1959). Care should be taken during processing to minimize the seed mortality that results from bruising or cracking the seedcoat.

For eastern hemlock, 0.35 hl (1 bu) of cones weigh about 15.5 kg (34 lb) or 1 liter (1 qt) of cones weights 0.44 kg (1 lb) (Eliason 1942) and yields 0.6 to 0.7 kg (1.4 to 1.5 lb) of seeds with a moisture content of 7.1% (Hill 1969; Toumey and Korstian 1952). Eastern hemlock seed yield per 100 kg (220 lb) of cones is 3.1 kg to 6.2 kg (6.8 to 13.6 lb) of seeds (Barton 1961; Ruth 1974). For western hemlock, there were 20,000 cones in 0.35 hl (1 bu) (Kummel and others 1944) and 0.45 kg (1 lb) of seeds was extracted from 0.35 hl (1 bu) of cones (Toumey and Korstian 1952).

Annual seeding and planting programs are dependent on successful seed storage (table 5). Western hemlock seeds keep best below freezing, and general practice is to store them at –18 °C. Barton (1954a) showed that viability was maintained better at this temperature than at –11 or –4 °C, with distinct differences showing up after only 2 years of storage. Viability can be maintained for at least 5 years, and this generally bridges the gap between large seedcrops.

Eastern hemlock seeds are stored both above and below freezing. They have been kept for 2 to 4 years in jars or plastic bags in a refrigerator maintained a few degrees above freezing, but retention of viability varied between seedlots (Olson and others 1959).

Mountain hemlock seeds are also stored at –18 °C. Mountain hemlock seedlots vary in their ability to withstand short-term stress, indicating that the genetic makeup of the seedlot may affect long-term seed storage. Accelerated aging (37.5 °C) treatments, varying from 0 to 21 days at 3-day intervals on mountain hemlock seeds, resulted in a complete loss of viability for stratified seeds at 12 days and for unstratified seeds at 18 days (El-Kassaby and Edwards 1998). The average viability for stratified seedlots decreased from 88% before aging to 3.6% after 9 days of aging. The average viability for unstratified seedlots decreased from 91% to 2% over the same time period (El-Kassaby and Edwards 1998).

Table 5—*Tsuga,* hemlock: seed storage conditions

Species	Seed moisture (%)	Temp (°C)	Viable period (yrs)
T. canadensis	—	5	4
	6–8	1–3	—
	—	–3	—
T. heterophylla	7–9	–18	5–7
	6–8	0	—
	8	–18	5+
	8	–18	3+
	—	21	2–3

Sources: Allen (1957), Barton (1954b, 1961), Jones (1962), Ruth (1974).

Moisture content of hemlock seeds in storage should be maintained between 6 and 9%. In longevity tests of seedlots stored at 5 °C with 6 to 10% moisture contents, a seedlot of western hemlock had 13% germination after 15 to 16 years, and another of mountain hemlock had 2% after 11 to 20 years (Schubert 1954). A study with western hemlock (Lavender 1956) demonstrated that temperatures and humidity levels generally experienced between removal of seeds from storage and seeding operations or testing procedures do not appreciably reduce viability. There was good viability retention of seeds removed from storage and stored at 20 °C and 30% relative humidity for as much as 11 weeks.

Pregermination treatments. Dormancy is variable in hemlock, with some seedlots requiring pregermination treatment and others germinating satisfactorily without treatment (Baldwin 1934; Bientjes 1954; Olson and others 1959). Because cold stratification (1 to 4 °C) of mature seeds shortens incubation time and may substantially increase germination, cold stratification is recommended prior to testing (except for seeds known to be nondormant) (table 6).

Stratification clearly accelerates and improves total germination of eastern hemlock (Baldwin 1930, 1934; Stearns and Olson 1958). For eastern hemlock seeds that have not been stratified, germination is improved by exposing seeds to 8- to 12-hour photoperiods at a temperature of about 21 °C alternating with dark periods at about 13 °C (Olson and others 1959). A long stratification period (70 days) increased germination percentages for Coffman (1975), who germinated seeds at 18 °C in darkness or with a $^1/_2$ hour of red light daily (615 nm, 0.056 g-cal/cm^2/min). Viable stratified, irradiated seeds showed 58% germination; viable stratified, non-irradiated seeds showed only 37%. Coffman also found that gibberillic acid (GA), kinetin, or a mixture of the two, inhibited the effect of prechilling, even in the presence of red light. There was nearly a complete lack of germination of unstratified eastern hemlock seedlots kept under red light (Coffman 1975).

Table 6—*Tsuga*, hemlock: stratification treatments

Species	Medium	Temp (°C)	Time (days)
T. canadensis	Moist sand or peat	1–5	30–120
T. caroliniana	Peat moss	3–5	30–90
T. heterophylla	Moist sand	1–5	21–90
	Plastic bag*	1–2	21–56
T. mertensiana	Moist sand	5	90

Sources: Allen (1958), Babb (1959), Deffenbacher (1969), Devitt and Long (1969), Eide (1969), Olson and others (1959), Ruth (1974), Swingle (1939), Walters and others (1960), Ward (1969), Weyerhaeuser (1969).
* Seeds were presoaked in tap water for 24 to 36 hours.

Germination of eastern hemlock seeds declines depending on the frequency and degree of drying following the imbibition phase and on the intensity of light. Eastern hemlock seeds incubated in open petri dishes at a low light level (645 lux) showed various germination values, from 50.2% with decomposed birch medium to 0% with filter paper. Seeds incubated in open petri dishes with decomposed birch medium that were exposed to a moderate light level (4,682 lux) exhibited delayed initial germination and significantly reduced total germination to half that at low light conditions (Coffman 1978). The intensity of light had no effect on seeds in covered petri dishes where a high moisture content was maintained.

Seeds of western hemlock stratified for 3 weeks at 1 °C germinated faster than untreated seeds; longer stratification periods caused additional but smaller increases in the rate of germination (Bientjes 1954; Ching 1958). Stratification of western hemlock seeds apparently has its main effect on speed of germination; it has only a minor effect on total germination percentage. Seedlots stratified for 1 week reached R_{50} (the number of days to reach 50% germination) 2.5 days sooner than did unstratified seedlots. Seedlots stratified for 4 weeks reached R_{50} 4.5 days sooner, and seedlots stratified for 16 weeks reached R_{50} 10.5 days sooner than did unstratified seedlots (Edwards 1973). Unstratified seedlots of western hemlock required nearly 2.5 weeks (18 days) to produce the same number of germinants as did seedlots stratified for 3 months in 10 days (Edwards 1973). Western hemlock seeds stratified for 1 week in plastic bags germinated about 1 day sooner than seeds stratified on filter paper (Edwards 1973). Presoaking the seeds for 48 hours was as effective in reducing the germination rate as was 1 week of stratification on filter paper (Edwards 1973). Immature western hemlock seeds tend to have lower total germination as a result of stratification (Allen 1958).

Experiments in Great Britain showed slightly increased rates of germination following stratification when western hemlock seeds were exposed to light but none when they were germinated in darkness (Buszewicz and Holmes 1961). Stratified western hemlock seeds tended to reduce the sensitivity to photoperiod (Edwards and Olsen 1973). Germination rate increased under a 4-hour photoperiod (300 to 350 foot candles or 3,228 lux); whereas 16 hours or more of photoperiod depressed germination rate below those in complete darkness at a constant 20 °C temperature (Edwards and Olsen 1973). Eight hours of light did not have a difference in germination from the no light treatment (Edwards and Olsen 1973).

Light significantly reduces germination rate for mountain hemlock seeds regardless of stratification. Unstratified and stratified seeds germinated in 8 hours of light (100 lux at filter paper surface) a week later than seeds grown in darkness (Edwards and El-Kassaby 1996). The R_{50} values for seeds incubated in light was almost double (6 days more) that of seeds incubated in darkness (Edwards and El-Kassaby 1996). Stratification increased the speed of germination slightly, but it did not alleviate the light effect nor did it effect total germination (Edwards and El-Kassaby 1996). Mountain hemlock seeds germinated 91% in the dark and 90% with light: mountain hemlock seeds can germinate as well or better without light (Edwards and El-Kassaby 1996).

Germination may begin while seeds are still in stratification if kept too long, with subsequent problems of drying out and mechanical damage during sowing. Careful regulation of seed moisture content and temperature can prevent germination from beginning in stratification. Seeds need to be kept at full imbibition but surplus water should be totally or mostly removed. Radicals will only elongate with surplus water present. Keeping temperatures closer to freezing and constant is also a good precaution. Temperature in the 1 to 2 °C range will retard germination more effectively than allowing temperatures to rise to near 5 °C. Personnel should limit entry into the stratification cooler to minimize temperature fluctuations.

Germination tests. The Association of Official Seed Analysts (AOSA 2001) have prescribed standard germination test conditions for eastern and western hemlocks (table 7). It is recommended that eastern hemlock seeds be prechilled for 28 days at 3 to 5 °C followed by 28 days in a germinator at 15 °C. The rules call for placing western hemlock seeds directly in germinators at 20 °C for 28 days. Stratification is not required as part of the standard germination test procedure for western hemlock seeds but a paired germination test with 21 days of stratification can be performed and it is common practice to stratify seeds prior to nursery sowing. Seeds of both species should be exposed to light no more than 8 hours daily during this period. A tetrazolium staining technique for estimating seed viability may be used on western hemlock, but results may tend to underestimate seed quality (Buszewicz and Holmes 1957).

The International Seed Testing Association (ISTA 1999) rules used for exporting seeds are similar to domestic rules except that the germination test period for western hemlock is extended to 35 days. Standard procedures have not been developed for Carolina and mountain hemlock, so test conditions follow those for the associated eastern or western hemlocks.

Mountain hemlock seed germination is very sensitive to the total accumulation of heat even though it has been known to germinate on snow but much more slowly (Franklin and Krueger 1968). Stratification as long as 120 days does not compensate for sub-optimal temperatures. For mountain hemlock seed testing germination, stratification for 90 days at 4.5 °C is recommended with germination temperature set at a constant 20 °C (480° daily heat sum) (table 6).

In a laboratory study, as the heat sums rose from 280 to 440% daily heat sums the germination rate increased but final germination was not affected by temperature (El-Kassaby and Edwards 2001). Heat sum is the addition of temperatures above 0 °C for 24 hours. The threshold heat sum for mountain hemlock seed germination lies close to 400% daily heat sum which does not occur at high elevations until August in British Columbia, Canada (El-Kassaby and Edwards 2001). Stratification treatments did not have a significant effect on rate or final germination (El-Kassaby and Edwards 2001).

Correlations between latitude and total germination (r= 0.482) and between mountain hemlock seed weight and latitude (r = – 0.482) were found to be significant (*p* less than

Table 7—*Tsuga*, hemlock: stratification period, germination test conditions, and results

Species	Cold stratification* (days)	Daily light period (hrs)	Germination test condions† Temp (°C) Day	Night	Days	Germination rate (%)	Germination rate (days)	Germination (%)	Samples
T. canadensis	60–120	—	30	20	60	10–55	15–30	38	15
	0–30	—	22	22	—	6–62	28	10–66	9–12
	21–30	8	16	16	28	—	—	—	—
	20	8	15	15	28	—	—	60	3
	40	8	15	15	28	—	—	45	3
	90	8	15	15	28	—	—	61	9
T. caroliniana	0	8	30	20	28	—	—	40–80	9
	21–30	8	30	20	28	—	—	51–57	3
	0–120	16	22	22	34	—	—	82–91	5
T. heterophylla	0	8	20	20	28–35	49	21	53	146
	0–90	—	16	11	30	38	20–30	56	25
	0	8	15	15	35	—	—	86	44
	28	8	15	15	35	—	—	86	43
T. mertensiana	0–90	—	30	20	25–30	62–75	16–20	47	4
	—	Dark	20	20	28	—	—	91	19
	—	8	20	20	28	—	—	90	19
	90	—	30	20	60	61	16	62	1
	0	8	20	20	28	—	—	81	4
	28	8	20	20	28	—	—	97	3
	90	8	20	20	28	—	—	72	5

Sources: AOSA (2001), Buszewicz and Holmes (1961), Edwards and El-Kassaby 1996, Hill (1969), ISTA (1999), Ruth (1974), USDA FS (2002)
* Temperatures were –16 to –15 °C.
† Moisture-holding media were either blotters, Kimpak®, sand, or peat.

or equal to 0.05) (Edwards and El-Kassaby 1996). As seed source was moved further north in latitude, the seed weight decreases because the seeds are smaller. Germination parameters are under strong genetic control with broad sense heritabilities, h_2, ranging from 0.30 to 0.85 for stratified seeds and 0.45 to 0.84 for unstratified seeds (El-Kassaby and Edwards 1998).

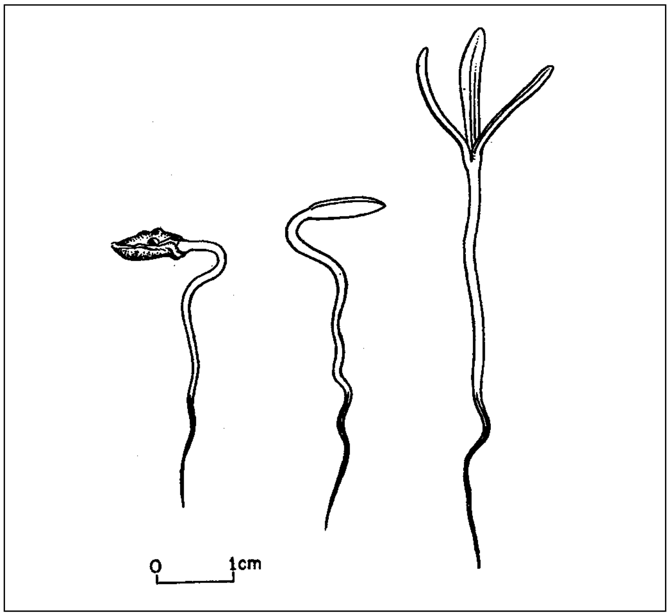
Final germination percentage of western hemlock seeds is affected by germination temperature. Greater total germination occurred at a constant temperature of 20 °C than under lower, higher, or alternating temperatures (Bientjes 1954; Buszewicz and Holmes 1961; Ching 1958). When alternating temperatures are used, keeping seeds in the dark improves germination (Buszewicz and Holmes 1961).

Western hemlock seeds from northern populations tended to germinate early, by about 4 days/degree of latitude, at 7 °C after 10 days of chilling (Campbell and Ritland 1982). Western hemlock seeds from high-elevation populations in the coast range germinated more rapidly than seeds from low or middle elevation population. For populations in the Cascades, seeds from both high- and low-elevation sources germinated more rapidly than seeds from middle elevations (Campbell and Ritland 1982). Lengthening stratification tended to decrease differences among provenances.

Observations of eastern hemlock (Olson and others 1959) illustrate ontogeny of seed germination, which is epigeal (figure 4). The first indicator of a viable seed is splitting of the seedcoat for half to two-thirds of its length, followed by the appearance of the pointed, bright-red root tip. The root grows at the rate of 2 to 3 mm/day, curving abruptly after emergence. After a few days, the hypocotyl also begins to grow, reaching 2 to 3 cm in length in 1 to 3 weeks. Normally, there is a pause in development after the cotyledons open, which may arbitrarily be considered the end of germination.

Nursery practice. Hemlock seedlings are difficult to grow in the nursery. They are easily damaged in the hot sun, and their small size the first year makes them particularly susceptible to frost heaving. Because of these difficulties, natural regeneration has in the past been favored over planting seedlings. Natural regeneration of western hemlock usually has been adequate, and a common procedure for mixed stands is to plant or seed associated species and expect hemlock to come in on its own, which it usually does. With increasing intensity of management, demand for western hemlock seedlings has increased, and production procedures were developed (Deffenbacher 1969; Devitt and Long 1969; Eide 1969; Isaacson 1969; Ward 1969; Weyerhaeuser 1969).

Figure 4—*Tsuga canadensis*, eastern hemlock: seedling development at 2, 4, and 7 days after germination.



At some nurseries (Eide 1969; Weyerhaeuser 1969), western hemlock seeds are soaked for 24 to 36 hours prior to stratification. The speed of germination was increased by soaking seeds in tap-water for 33 hours at room temperature (Bientjes 1954). Prolonged soaking for 96 to 120 hours, however, reduced the germination rate (Ching 1958).

Most nursery managers stratify western hemlock seeds and sow them in the spring. Seeds are moistened, excess water drained off, then the seeds are stratified at 1 to 2 °C from 21 to 42 days in a polyethylene bag. No stratification medium is used. Seed moisture content for optimum germination should be about 60% (Devitt 1969). Soil moisture content should be high but with drainage adequate to keep the ground water level below the rooting zone. Seedbeds may need screening to protect seeds from birds and rodents.

At one nursery (Eide 1969), seeds were sown on the surface and covered with burlap and sprinkled as needed to maintain moisture. After germination and penetration of the radicle into the soil, the burlap is removed and seedlings are mulched with peat moss. Additional peat moss is added during the growing season. Seedlings go into the winter with 13 to 19 mm ($^1/_2$ to $^3/_4$ in) of mulch to minimize frost heaving. About 50% shade is provided the first season.

For nursery production of eastern hemlock seedlings, spring-sowing of stratified seed is preferred over fall-sowing (Hill 1969; Olson and others 1959). Good eastern hemlock seeds planted under favorable conditions usually survive superficial contamination with mold, and use of fungicides is not recommended unless serious contamination is present. Nursery seedlings are very subject to damping-off by *Rhizoctonia* spp. during the first few months after germination and this can be aggravated by over-fertilization. It can be prevented (and weed seeds killed) with fumigation. Damping-off after germination can be controlled with fungicide (Olson and others 1959). One nursery growing western hemlock treats seedbeds when necessary with captan or thiram and has not had a serious problem with damping-off diseases. They also have treated hemlock seedlings with animal repellant to protect them from damage after outplanting (Eide 1969).

In nursery experiments in Great Britain, partial soil sterilization with formalin drench or chloropicrin injection improved growth of western hemlock. Moderate to large height increases were obtained with either treatment. Both sterilants used together often gave even better growth response, although treatment effects were not additive (Benzian 1965).

Only a few reports are available on nutrient requirements of hemlock. Western hemlock in British Columbia requires a well-drained acid soil with pH about 4 to 5 and an organic matter content of 5 to 6% (Devitt 1969). In Washington, it grows well at pH 5.3 to 5.4 with at least 15% soil organic matter (Eide 1969). In Great Britain, western hemlock made maximum growth on acid soil at about pH 4.5 and responded favorably to fertilization with nitrogen, phosphorus, and potassium. It showed a definite tip burn when suffering a copper deficiency, but seedlings recovered when sprayed with Bordeaux mixture. Water deficits during a dry summer apparently prevent response to nitrogen fertilization (Benzian 1965), but on the other hand, late summer watering can delay hardening-off and may increase the risk of frost damage (Olson and others 1959).

Seedlings are small at the end of the first growing season in the nursery and usually are held over and lifted after the second or third season. Seedlings frequently are transplanted for 1 year and then outplanted as 2+1 or 3+1 planting stock (Devitt and Long 1969; Olson and others 1959; Ward 1969). To overcome the difficulties of germination and frost heaving in the bareroot bed, plug+1 or plug+2 seedlings are used more commonly now than directly sowing seeds in the nurserybed (Romeriz 1997). In this system, a miniplug seedling is started in the greenhouse and then transplanted to the bareroot nurserybed.

Desired densities range from 323 to 538 seedlings/m^2 (30 to 50/ft^2) and tree percentages run from 15 to 50 (Deffenbacher 1969; Devitt and Long 1969; Eide 1969; Isaacson 1969; Ward 1969; Weyerhaeuser 1969). Experience in Great Britain indicates that a large proportion of losses in the nursery occur before seedling emergence. A high variability in tree percentage requires large safety factors in nursery sowings, resulting in an occasional surplus of seedlings (Buszewicz and Holmes 1961). The use of western hemlock plug transplants (Klappart 1988) reduces the number of seeds used and produces a larger, higher quality seedling in less time (Smith 1997). The production of container seedlings for outplanting is also widely practiced for western hemlock (Smith 1997).

Most hemlocks are now grown in containers in greenhouses under intensive culture instead of in bareroot nurseries. Styrofoam® blocks are the most common containers used and the sizes vary from 60, 77, to 112 trees/block with 77 trees/block the most commonly used. There are two outplanting regimes that dictate the propagation procedure in the greenhouse. The spring-planting regime requires that seeds be sown around February 1st, with the seedlings outplanted in the spring of the next year. Seeds are sown around January 15th for the summer-planting regime, with the seedlings being outplanted in the summer of the same year (Girard 2002).

Seeds are stratified for 21 days before sowing to achieve rapid, uniform germination and are germinated at 20 to 25 °C with light. It is the usual practice to sow with equipment more than 1 seed per cavity when germination falls below 90%. Once the seeds are fully germinated the photoperiod is increased to 20 hours/day and maintained until late April to keep the terminal bud from setting prematurely. The container medium is usually peat moss that may be amended with perlite or fir sawdust. Containers are lightly filled with medium to allow hemlock's large root system to grow. Controlled-release fertilizer is added to the medium at 4 kg/m^3 of medium in addition to lime to raise the pH and trace elements. The seeds are lightly covered with a sandy grit. A complete soluble fertilizer is added to the irrigation water every time the seedlings are watered. Frequency of irrigation is determined by weighing the containers after watering and then re-irrigating once the container weight drops below the target level (Girard 2002).

The seedlings are induced to set a terminal bud in the greenhouse by photoperiod reduction achieved through retractable darkout systems. Western hemlock seeds from southern sources require about a 4-week darkout period of 10 hours/day of light and 14 hours/day darkness. Seeds from northern sources only require about 2 weeks of darkness in the July following sowing to set buds. The short-day induction period is not begun until the trees have reached a minimum height of 15 cm (77 cavities/block). Seedlings will continue height growth during the short-day treatment so it is important to initiate bud induction early enough to maintain a good shoot to root ratio. Following the darkout period, seedlings are subjected to moderate moisture stress to maintain budset. Nurseries favor greenhouse systems that have roofs that open to subject the planting stock to full light conditions following budset. In nurseries lacking those systems, containers are usually moved outside growing compounds (Girard 2002).

For 77 cavities/block stocktypes, the target seedling height for outplanting is 30 cm (12 in), with no more than a maximum of 40 cm (16 in) height. The minimum caliper for outplanting is 3 mm and the target is 3.5 mm. It takes about 25 weeks from sowing to grow a target seedling. For spring-planted crops, ambient greenhouse temperatures are reduced to about 2 °C in the late fall to further develop dormancy. A frost hardiness test is performed to determine dormancy before the seedlings are lifted for cold storage. A sample of seedlings are frozen to –15 °C and injury is determined through variable chlorophyll inflorescence (Girard 2002).

For extraction of seedlings from the growing containers, most nurseries use automatic pin extractor machines. The containers are laid on their sides and metal pins push the plugs out of the containers and the seedlings are then graded for quality. For summer outplanting (late August and early September), seedlings are not stored before planting. The seedlings are lifted while still growing, shipped, and planted within 24 hours (Girard 2002).

Spring-outplanted seedlings are lifted from containers in December and stored for up to 3 months in cold storage at –2 to –5 °C. Seedlings are placed in an upright position within a waxed cardboard box. Boxes filled with seedlings to be stored frozen have a brown paper liner with an inner plastic membrane to retain moisture. Frozen seedlings are allowed to thaw 3 to 5 days in a thawing shed before they are shipped to the field for planting (Girard 2002).

Eastern hemlock is sometimes propagated vegetatively. Dormant cuttings taken in January to mid-February should be placed in beds with bottom heat, but results can be variable (Dirr and Heuser 1987).

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U

Fabaceae—Pea family

Ulex europaeus L.

common gorse

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Growth habit, occurrence, and use. Gorse is a leafless, spined shrub introduced from western Europe. In its homeland, it grows 1 to 2 m tall and is primarily a non-aggressive invader of disturbed areas that is recognized as useful for wildlife protection, soil stabilization, and revegetation. It has also been cultivated as an ornamental and as forage for livestock, which feed on the soft, new growing shoots. Its major use in the past, however, was for hedgerows to contain livestock before barbed wire (Jobson and Thomas 1964). As a useful plant, European settlers carried gorse to many parts of the world where it quickly escaped from cultivation and formed aggressive feral populations. These feral plants grow 3 to 5 m tall in dense, spiny, impenetrable stands that exclude desirable vegetation in pasture lands (Hill 1983; Sandrey 1985) and, in open forests, interfere with reforestation and forest management (Balneaves and Zabkiewicz 1981; Zabkiewicz 1976). Gorse is presently recognized as one of the worst weeds in New Zealand, Chile, and Tasmania and is recognized as a weed in at least 15 other countries or island groups around the world (Holm and others 1979).

In North America, gorse is still used to a limited extent as an ornamental for its dense yellow flowers. In the eastern United States, scattered feral populations have been recorded, but apparently these are not of an aggressive nature. By contrast, along the Pacific Coast, gorse is found scattered along the coastline from San Francisco, California, north to Vancouver, British Columbia (Markin and others 1994). Through most of this area, it is found in small, scattered populations that are usually targeted for intensive control programs to keep them from expanding. The major outbreak along the southwestern coast of Oregon covers at least 15,000 ha and is a major problem in forest management. This gorse population interferes with reforestation and, because of the plant's highly flammable nature, creates an extreme fire hazard (Herman and Newton 1968). Gorse also infests 14,000 ha at higher elevations on the islands of Hawaii and Maui in Hawaii (Markin and others 1988).

As a useful agricultural and ornamental plant in its native range, methods for propagating gorse have been developed in Europe (Rudolf 1974). As a major weed through the rest of the world, no effort has been made to propagate it for sale or outplanting. However, very extensive work has been done in studying the regeneration, reproduction, and propagation of this plant for research purposes and to develop control methods, particularly in New Zealand. A more recent need has been to propagate gorse to be used as food for insects being tested as potential biocontrol agents (Markin and Yoshioka 1989).

Flowering and fruiting. The small, bright yellow, pea-like flowers (Whitson and others 1991) are very similar in size and appearance to those of the closely related Scotch broom—*Cytisus scoparius* (L.) Link—with which it shares much of its range on the Pacific Coast. In Europe, gorse blooms in late spring, usually for 1 month; depending upon the latitude, this can occur from late February to early June. On the Oregon coast, gorse blooms from February to early May; in Hawaii, it blooms from December to May, peaking in February and April. Flowers may be solitary or in clusters, but because they are often synchronized in blooming, an entire plant will sometimes be covered with thousands of blooms. The flowers are insect-pollinated and require a large insect that, while probing for nectar, can trip and release the stamens held in the keel on the lower surface of the flower. The major pollinator in North America and Hawaii is the common honey bee (*Apis mellifera* L.). When massive blooms occur in areas where feral bees are scarce, poor pod set may be seen in limited areas (a desirable feature for land managers). Beekeepers, however, recognize the bloom as an excellent source of early spring pollen that can be used to build up their hives, and they usually move hives in to take advantage of the bloom, resulting in adequate pollination (Sandrey 1985). One method of control that has been used in Hawaii is restricting commercial bees in an effort to reduce seed production.

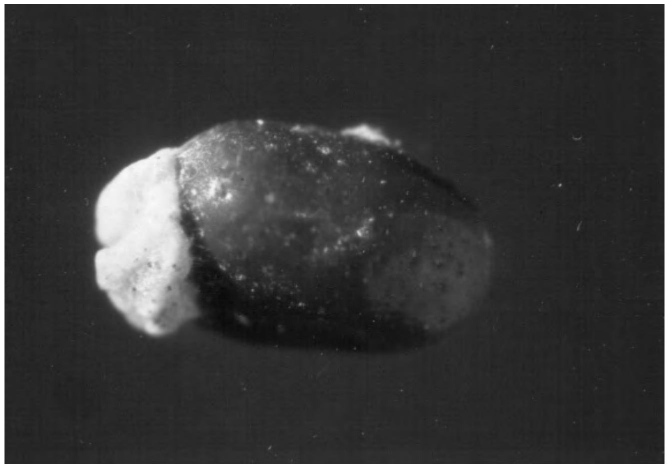
The mature fruit is a typical, small (1 to 1.5 cm), black legume (pod) that contains 1 to 12 seeds, although the average is 4 to 5. After pollination, a legume requires 2 months to mature, so peak legume set occurs 2 months after peak flowering. In Oregon, this is mid-May through July; in Hawaii, peak legume set is in May and is finished by the first of July. On maturing and drying, the legumes open violently (dehisce), naturally dispersing the seeds 1 to 3 m out from the parent plant. In Oregon and Hawaii, natural germination usually occurs during the wetter winter and spring months.

Fruit collection; seed extraction and storage. As an aggressive, noxious weed, there is no demand for the commercial collection of seeds. Researchers obtain the seeds they need by collecting the mature black legumes individually or by cutting a branch containing them. When allowed to dry out in a cloth sack at room temperature, the legumes naturally dehisce, releasing the seeds. The mature brown seeds are generally spherical, 1.25 to 2 mm in diameter (figure 1). Each seed initially contains an elaiosome, a yellow, fleshy appendage, rich in oil and protein (Pemberton and Irving 1990) that attract ants; this is another method of seed dispersal (Weiss 1909). The gorse seedcoat is notorious for its hardness (it is water impermeable), which gives the seeds a very long field life and has created major problems in managing this weed (Butler 1976; Chater 1931; Moss 1959). Seed numbers range from 145,000 to 159,000/kg and average about 150,000/kg (66,000 to 72,000/lb and average about 68,000/lb) (Rudolf 1974). The seeds are orthodox in storage behavior and can be kept indefinitely in ordinary cool, dry storage.

Pregermination treatments. Germination of mature, well-dried seeds varies greatly according to the literature but can be as low as 10 to 30% in 6 months. In the field, the seeds have a long life; it has been estimated that they can remain viable for up to 26 years or more (Moss 1959).

Because of the seedcoat's hardness, a number of different pregermination treatments have been tried. In the field, the most common method to trigger germination is fire. When a gorse area burns, the seeds in the top centimeter or two of duff are destroyed, but the deeper seeds survive and most of these are often triggered into germinating (Rolston and Talbot 1980; Zabkiewicz and Gaskin 1978). In the laboratory, this can be duplicated by heating the seeds from 60 to 80 °C for 30 minutes in an oven (Butler 1976; Moss 1959). Placing gorse seeds in boiling water for 30 seconds and then cooling them in cold water can increase germination to over 90% (Millener 1961).

Figure 1—*Ulex europaeus*, common gorse: seed.



Other methods of germination include soaking in concentrated sulfuric acid for $^1/_2$ to $1^1/_2$ hours, and mechanical scarification (Buttler 1976), most simply done with emery paper (Moss 1959).

Germination tests. Because of the noxious nature of gorse in North America, standardized germination tests for quality control have not been developed. In Europe, where gorse is a beneficial native plant, germination tests at one time were apparently developed in which seeds were tested in germinators or sand flats at 20 °C for 30 days using 400 pretreatment seeds/test (Rudolf 1974). Researchers have reported no problem in obtaining germination by planting scarified seeds 1 cm deep in different media. First signs of germination are usually seen within 10 days of planting. In 15 to 25 days, seedlings are small rosettes with true leaves, approximately 1.5 cm in diameter. Small leaves continue to form until the plant is approximately 5 cm tall, at which time the first spines are produced. During the remainder of its life, the plant produces no more leaves, only spines. The juvenile stage of the plant, from seed germination until spines begin to form, requires 4 to 6 months in the field. In Europe, large-scale germination in pots and direct seeding into the field have been practiced in the past (Rudolf 1974).

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Ulmaceae—Elm family

Ulmus L.

elm

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Growth habit, occurrence, and use. About 20 species of elm—the genus *Ulmus*—are native to the Northern Hemisphere. There are no native elms in western North America but some are found in northeastern Mexico (Johnson 1973). American elms are much loved as street trees for their arching branches and most elms species are valued for their hard, tough wood and many have been planted for environmental purposes. The natural ranges of 13 of the more important species are listed in table 1.

Since the 1930s, however, most elms in North America have been killed by the Dutch elm fungus, *Ophiostoma ulmi* (Buisman) Nannf., or by phloem necrosis, which is caused by a microplasma-like organism (Sinclair and others 1987). The Dutch elm disease was discovered in 1930 in Ohio. Dutch elm disease is transmitted when the European elm beetle, *Scolytus multistriatus* (Marsham), and the native elm bark beetle, *Hylurgopinus rufipes* Eichoff, feed on the tree (Burns and Honkala 1990). Phloem necrosis is spread by the

Table 1—*Ulmus*, elm: nomenclature and occurrence

Scientific name & synonym(s)	Common name(s)	Occurrence
U. alata **Michx.**	**winged elm,** cork elm, wahoo	Virginia to Missouri, S to Oklahoma & E Texas, E to central Florida
U. americana **L.**	**American elm,** water elm, soft elm, white elm	Quebec to E Saskatchewan, S to North Dakota, Oklahoma, & Texas, E to central Florida
U. crassifolia **Nutt.**	**cedar elm,** basket elm, red elm, southern rock elm	SW Tennessee, Arkansas, & S Oklahoma to S Texas, Louisiana & W Mississippi
U. glabra **Huds.** *U. scabra* Mill. *U. montana* With. *U. cammpestris* L. in part	**Scots elm,** Scotch elm, Wych elm	N & central Europe & Asia Minor
U. japonica **(Sarg. ex Rehd.) Sarg.** *U. campestris* var. *japonica* Rehd. *U. davidiana* var. *japonica* (Rehd.) Nakai	**Japanese elm**	Japan & NE Asia
U. laevis **Pall.** *U. pedunculata* Pall. *U. effusa* Willd.; *U. racemosa* Borkh.	**Russian elm,** spreading elm, European white elm'	Central Europe to W Asia
U. minor **Mill.** *U. carpinifolia* Gled.	**Smoothleaf elm,** field elm,	Central & S Europe, England, Algeria, & Near East
U. parvifolia **Jacq.** *U. chinensis* Pers.	**Chinese elm,** leatherleaf elm, lacebark elm	N & central China, Korea, Japan, & Formosa
U. procera **Salisb.**	**English elm**	S & central England, NW Spain
U. pumila **L.**	**Siberian elm,** Chinese elm, dwarf Asiatic elm	Turkestan, E Siberia, & N China
U. rubra **Mühl.** *U. fulva* Michx.	**slippery elm,** grey elm, red elm, soft elm (lumber)	SW & Quebec to E North Dakota, S to W Oklahoma & SE & E Florida
U. serotina **Sarg.**	**September elm,** red elm	Kentucky and S Illinois, S to N Alabama & NW Georgia; also in Arkansas & E Oklahoma
U. thomasii **Sarg.** *U. racemosa* Thomas	**rock elm,** cork elm	Vermont to S Ontario, central Minnesota & SE South Dakota, S to E Kansas, E to Tennessee & New York

Sources: Brinkman (1974), Maisenhelder (1966), Rudolf (1937).

whitebanded elm leafhopper, *Scaphoideus luteolus* (Van Duzee) and root grafts (Burns and Honkala 1990). Only Chinese, Japanese, and Siberian elms (Krüssman 1960) are resistant to these diseases. Although American elms now are only a small percentage of the large-diameter trees in mixed forest stands, beautiful old specimens of American elm still exist in some isolated city parks and along streets, for example, in Central and Riverside Parks in Manhattan (Barnard 2002).

Flowering and fruiting. Elm flowers are perfect. Selfing rarely occurs in elms due to their high degree of self-incompatibility, with the exception of Siberian elm, which is self-compatible (Townsend 1975). American elm has twice as many chromosomes (2n = 56) as the other elm species common to North America, making it hard to cross-pollinate different species to impart disease resistance to American elm (Burns and Honkala 1990).

Most of the elms commonly grown in North America have protogynous flowers, where the stigma becomes receptive to pollen before the male anthers dehisce (Burns and Honkala 1990). Three species—rock, Siberian and Russian elms—have protandrous flowers, where the male anthers dehisce before the stigma is receptive. The elms are one of the few tree genera where the normal flowering period varies more than 2 to 3 weeks among species that are sexually compatible (Santamour 1989). Five floral stages have been identified: (1) stigma visible; (2) stigma lobes reflexed above anthers; (3) anthers dehiscing; (4) anther dehiscence complete and stigma wilting; (5) stigma shriveled, ovule green, and enlarged (Lee and Lester 1974). Pollination at stage 2 yielded the most viable seed (81%) followed by stage 1, stage 3, stage 4, and finally stage 5 (Lee and Lester 1974).

The perfect, rather inconspicuous inflorescences usually are borne in the spring before the leaves appear except for cedar, lacebark, and red elms, which flower in the fall (table 2). The inflorescences are fascicles, racemes, or racemose cymes measuring <2.5 up to 5 cm long (Fernald 1970). American, Scots, and rock elms have pendulous inflorescences (FNAEC 1997). Individual flowers are borne on pedicels measuring 0.4 to 1 cm long. The flowers have a calyx with 3 to 9 lobes, 3 to 9 stamens, and white stigmas with 2 styles (Fernald 1970; Radford and others 1968). Most of the elm species have reddish anthers,which gives the trees their characteristic flower color (FNAEC 1997; Johnson 1973).

The fruit is a 1-cell samara that ripens a few weeks after pollination and consists of a compressed nutlet surrounded by a membranous wing (figures 1 and 2). Winged, cedar, slippery, red, and rock elm seeds have pubescent samaras (Hora 1981). The seed is centrally located within the wing for slippery, Siberian, lacebark, and Scots elms (Hora 1981). The apex of the wing can be shallowly or deeply notched (FNAEC 1997). American elm seeds have 2 inward curving beaks at the wing's apex (Dirr 1998). Elm seeds have no endosperm and are dispersed by wind, water, or animals (Burns and Honkala 1990). Most species produce good seedcrops at 2- or 3-year intervals (table 3).

Collection of fruits. Elm seeds can be collected by sweeping them up from the ground soon after they fall or by beating or stripping the seeds from the branches. The large seeds of rock elm are greatly relished by rodents (Dore 1965), however, and usually must be picked from the trees. American elm samaras fall within 91 m of the parent tree (Burns and Honkala 1990). Rock elm samaras are carried no more than 40 to 45 m from the parent tree, but their buoyant

Table 2—*Ulmus*, elm: phenology of flowering and fruiting

Species	Location	Flowering	Fruit ripening	Seed dispersal	Seed size (mm)
U. alata	—	Feb–Apr	Apr	Apr	6–8
U. americana	From S to Canada	Feb–May	Late Feb–June	Mid-Mar–mid-June	13
U. crassifolia	SE US	Aug–Sept	Sept–Oct	Oct	6–13
U. glabra	Europe & Asia Minor	Mar–Apr	May–June	May–June	15–25
U. japonica	Japan	Apr–May	June	—	—
U. laevis	Massachusetts	Apr–May	May–June	May–June	10–15
U. parvifolia	NE US	Aug–Sept	Sept–Oct	Sept–Oct	10
U. pumila	E central US	Mar–Apr	Apr–May	Apr–May	10–14
U. rubra	F S to Canada	Feb–May	Apr–June	Apr–June	12–18
U. serotina	SE US	Sept	Nov	Nov	10–13
U. thomasii	NE US	Mar–May	May–June	May–June	13–25

Sources: Asakawa (1969), Brinkman (1974), Burns and Honkala (1990), Dirr (1998), FNAEC (1997), Hora (1981), Little and Delisle (1962), Loiseau (1945), Pammel and King (1930), Petrides (1958), Rehder (1940), Spector (1956), Stoeckeler and Jones (1957), Sus (1925) ,Vines (1960), Wappes (1932), Wyman (1947).

Figure 1—*Ulmus*, elm: samaras of *U. alata*, winged elm (**top left**); *U. americana*, American elm (**top right**); *U. parvifolia*, Chinese elm (**middle left**); *U. pumila*, Siberian elm (**middle center**); *U. rubra*, slippery elm (**middle right**); *U. crassifolia*, cedar elm (**bottom left**); and *U. thomasii*, rock elm (**bottom right**).

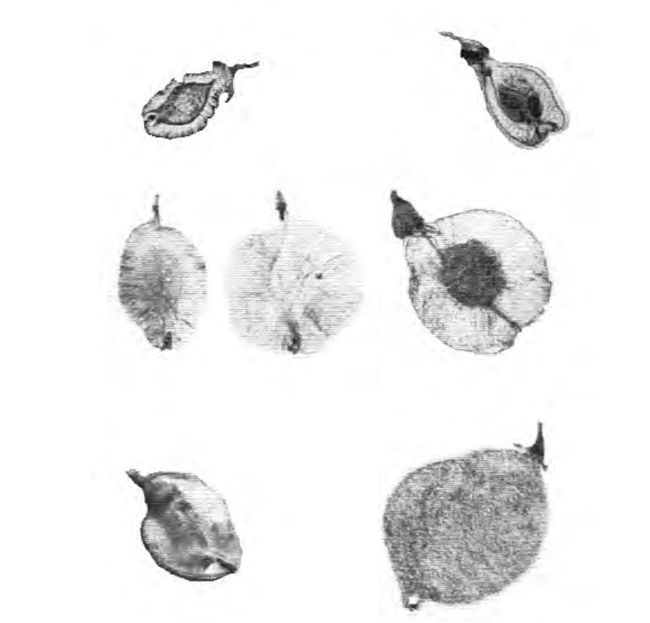


Figure 2—*Ulmus alata*, winged elm: longitudinal section through a seed.

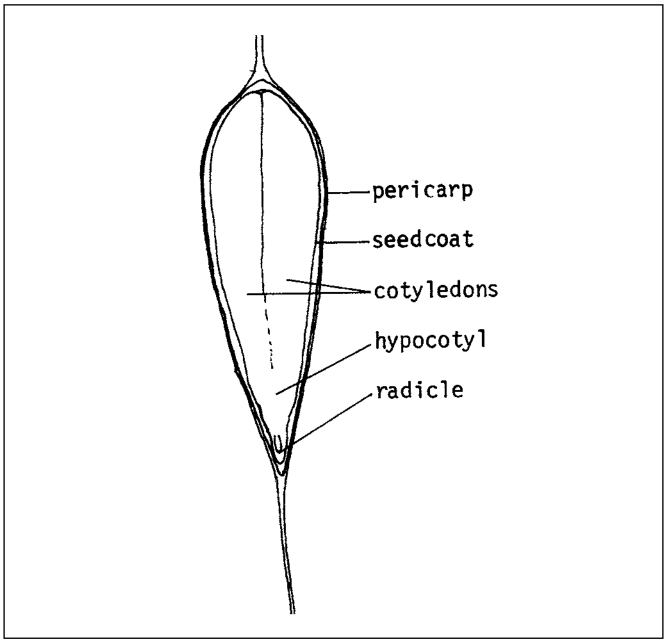


Table 3—*Ulmus*, elm: height, seed-bearing age, seed crop frequency, and fruit ripeness criteria

Species	Height at maturity (ft)	Year first cultivated	Minimum seed-bearing age (yr)	Years between large seedcrops	Ripe fruit color when ripe
U. alata	50	1820	—	—	Reddish green
U. americana	120	1752	15	—	Greenish brown
U. crassifolia	100	—	—	—	Green
U. glabra	130	Long cultivated	30–40	2–3	Yellow-brown
U. japonica	100	1895	—	2	—
U. laevis	100	Long cultivated	30–40	2–3	Yellow-brown
U. parvifolia	80	1794	—	—	Brown
U. pumila	80	1860	8	45	Yellow
U. rubra	70	1830	15	2–4	Green
U. serotina	60	1903	—	2–3	Light green to brownish
U. thomasii	100	1875	20	3–4	Yellow or brownish

Sources: Brinkman (1974), Burns and Honkala (1990), Dore (1965), FNAEC (1997), George (1937), Little and Delisle (1962), McDermott (1953), Van Dersal (1938), Vines (1960), Wappes (1932).

samaras can be carried by water and are frequently found along stream and lake banks (Burns and Honkala 1990). In rock elm, 90 to 100% of the mature seeds are viable and the seeds ripen about 2 to 3 weeks after American elm seeds (Burns and Honkala 1990).

Storjohann and Whitcomb (1977) collected lacebark elm seeds at Oklahoma State University and found that 75 to 80% of the seeds were empty. They also found that lacebark elm seeds are the most viable if collected before a hard freeze. Freshly collected fruits should be air-dried for a few days before being sown or stored. The number of seeds per weight varies widely, even within species (table 5).

Extraction and storage of seeds. Although the fruits can be de-winged by putting them into bags and beating with flails, this has been found to damage the seeds of American and Siberian elms (Cram and others 1966; George

1937). Elm seeds can be cleaned with an air-screen cleaner in a reverse procedure—blowing out the seeds, and catching the heavier leaves and twigs (Myatt 1996) with the air vents wide open on both sides of the cleaner. A large round-holed 9.9-mm screen (#25) is placed on top of the cleaner to separate the seeds from the leaves and a small round-holed 2.4-mm screen (#6) is placed on the bottom to separate the twigs from the seeds (Myatt and other 1998). Only 3 to 7% of the seeds blown out of the air chute in the back of the air-cleaner were good seeds (Myatt and others 1998).

Fruits usually are sown or stored with the wings attached. Elm seeds are orthodox in storage behavior and should be stored at low temperatures and moisture contents in sealed containers (table 4). Dessication of smoothleaf elm seeds to 3.3% moisture content did not reduce germination (Tompsett 1986). When the temperature of storage was increased at constant moisture contents, seed longevity was reduced within the range of –13 to 52 °C. Smoothleaf elm seeds stored at 22% moisture content (fresh-weight basis) died after 7 days at –75 C°, but seeds stored at 19% moisture content lost no germination ability. Lowering the storage temperature from –13 to –75 °C did not increase seed longevity. Tompsett (1986) found that a 5% moisture content and a temperature of –20 °C or lower maintains the long-term seed viability for smoothleaf elm seeds. Tylkowski (1989) reported that Russian elm seeds dried to 10% moisture could be stored at –1 to –3 °C for 5 years without losing any viability; however, after 6 years of storage, a 20% decrease in germination was observed. Siberian elm seeds with 3 to 8% moisture content have been stored at 2 to 4 °C in sealed containers for 8 years (Dirr and Heuser 1987). Air-dried Scots elm seeds stored at 1 to 10 °C were only viable for 6 months (Dirr and Heuser 1987).

Dried American elm seeds stored at 0, 10, and 20 °C declined from 65 to 70% germination before storage to less than 10% after 10.5 months of storage (Steinbauer and Steinbauer 1932). Another lot of dried American elms seeds stored at 20 °C exhibited a steady, continuous decline in germination when stored for 14 to 51 weeks compared to fresh seed germination values (Steinbauer and Steinbauer 1932). Barton (1939, 1953) found that a 75% germination value for American elm seeds was retained after 15 years of seed storage at –4 °C with a 3% seed moisture content .

Pregermination treatments. Under natural conditions, elm seeds that ripen in the spring usually germinate in the same growing season; seeds that ripen in the fall germinate in the following spring. Although seeds of most elm species require no presowing treatment, practically all the seeds in some seedlots of American elm remain dormant until the second season (Rudolf 1937). Dormant American elm seedlots should receive cold stratification for 2 to 3

Table 4—*Ulmus,* elm: seed storage conditions

Species	Seed moisture (%)	Storage temp (°C)	Viable period (yr)
U. alata	Air-dried	4	1
U. americana	3–4	–4	15
	Air-dried	4	2
U. crassifolia	Air-dried	4	1
U. glabra	Air-dried	1–10	0.5
U. laevis	Air-dried	22	0.5
U. parvifolia	10–15	0	0.5
U. pumila	3–5	2–4	8
U. thomasii	Air-dried	Cold	—

Sources: Barton (1939, 1953), Brinkman (1974), Heit (1967a&b), Kirby and Santelmann (1964), Rohmeder (1942), Sus (1925).

Table 5—*Ulmus,* elm: seed yield data

				Cleaned seeds (x1,000)/weight				
		Fruit/vol		Average		Range		
Species	Place collected	kg/hl	lb/bu	/kg	/lb	/kg	/lb	Samples
U. alata	Mississippi	—	—	245	112	222–269	101–119	4
U. americana	—	5.8	4.5	156	71	106–240	48–109	14
U. crassifolia	Mississippi	—	—	147	67	130–135	59–61	5
U. glabra	Europe	4–6.5	3–5	88	40	66–99	30–45	12+
U. japonica	Japan	—	—	12.8	6	—	—	2+
U. laevis	Russia	—	—	140	63	117–205	53–93	20+
U. parvifolia	US, Japan	—	—	265	121	250–372	114–169	6+
U. pumila	—	—	—	158	72	88–261	40–119	35+
U. rubra	—	—	—	90	41	77–119	35–54	10
U. serotina	—	—	—	328	149	—	—	—
U. thomasii	—	7.7–10.3	6–8	15	7	11–15	5–7	5

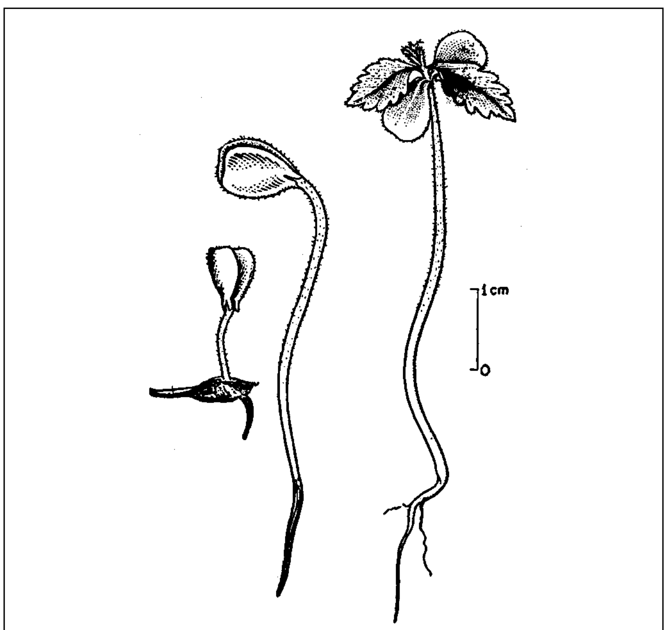
Sources: Asakawa (1969), Brinkman (1974), Engstrom and Stoeckeler (1941), Goor (1955), Gorshenin (1941), Heit (1969), Rafn and Son (1928), Stoeckeler and Jones (1957), Sus (1925), Swingle (1939), Taylor (1941), Van Dersal (1938), Wappes (1932).

months (Dirr and Heuser 1987). Seeds of slippery elm, especially from northern sources, also may show dormancy; 70% of fresh seeds germinated and 57% germinated after 2 months of cold, moist stratification (Dirr and Heuser 1987). Stratification at 5 °C for 60 to 90 days before sowing improves germination of cedar, smoothleaf, and September elms (Brinkman 1974; Dirr and Heuser 1987; Maisenhelder 1968).

Winged, Scots, Japanese, English, Russian, Siberian, and rock elms have no pregermination requirements (Dirr and Heuser 1987). Fresh seedlots of Scots elm germinated at 98%, but after 2 months of cold, moist stratification, only 88% germinated (Dirr and Heuser 1987). English elm rarely produces seeds, but fresh seeds will germinate at 100% with or without 2 months of stratification (Dirr and Heuser 1987). Fresh Siberian elm seeds germinated 96% and cold stratification did not improve germination (Dirr and Heuser 1987). Fresh lacebark elm seeds will germinate without pretreatment, but once dried they require 1 to 2 months of cold, moist stratification (Dirr and Heuser 1987).

Germination tests. Official testing rules for American elm call for alternating temperatures of 30 °C (day) for 8 hours and 20 °C (night) for 16 hours for 14 days on wet blotters and 10 days at a constant 20 °C for Chinese and Siberian elms (AOSA 2001). American elm seeds can also germinate well at alternating temperatures of 21 °C (day) and 10 °C (night) (Burns and Honkala 1990). The International Seed Testing Association (1999) suggests testing for 14 days on wet blotters for all 3 species. ISTA also suggests removal of the pericarp if germination is slow. Germination tests of most species may also be made on sand or peat in germinators at alternating temperatures of 30 °C (day) and 20 °C (night). Rock elm seeds germinated 70 to 80% in a peat moss medium (Burns and Honkala 1990). Light requirements may vary among species (table 6). American elm can germinate in darkness but germination is increased with the addition of light (Burns and Honkala 1990).

Figure 3—*Ulmus americana*, American elm: seedling development at 1, 3, and 21 days after germination.



Germination is epigeal (figure 3); it usually peaks within 10 days. Seedlots of stratified seeds complete germination in 10 to 30 days. With American elm seeds, germination can extend up to 60 days; seeds can lay on flooded ground for a month without adversely affecting germination (Burns and Honkala 1990). Radicles of rock elm emerge in 2 to 3 days in a petri dish and are 2.5 to 3.8 cm (1 to 1.5 in) long by the 5th day; cotyledons opened about the 5th or 6th day (Burns and Honkala 1990). Winged elms cotyledons are oval with shallowly notched apexes and heart-shaped bases and may persist 1 to 2 months on the seedling with primary leaves appearing 1 week after germination in natural forest conditions (Burns and Honkala 1990).

Nursery practice. Seeds of elm species ripening in the spring are usually sown immediately after collection, whereas seeds of fall-ripening species or of species requiring stratification are usually planted the following spring (table 7). Beds should be kept moist until germination is complete; shading is not usually necessary. From 5 to 12% of the viable cedar elm seeds sown can be expected to produce plantable stock (Burns and Honkala 1990). One-year-old seedlings usually are large enough for field planting. Rock elm seedlings have a persistent dormant bud, so seedlings rarely develop more than a single pair of true leaves in the first growing season (Burns and Honkala 1990). In northern Wisconsin, rock elm 1.5+0 nursery stock averaged 27 cm (10.6 in) in height 5 years after planting and 52 cm (20.5 in) in height 10 years after planting; first-year survival was 85% and 10th-year survival was 32% (Burns and Honkala 1990). To improve survival in semiarid regions, trees often are transferred into containers after 1 year in the seedbeds (Goor 1955). Slippery elm is commonly used as rootstock when grafting hybrid elms (Burns and Honkala 1990).

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Table 6—*Ulmus*, elm: germination test conditions and results

	Germination test conditions*				Germinative energy	Germinative capacity			
		Temp (°C)			Amount	Period	Avg		Purity
Species	Medium	Day	Night	Days	(%)	(days)	(%)	Samples	(%)
U. alata	Soil	32	21	15	76	7	91	6	—
U. americana	Paper pads	30	20	14	—	—	—	—	—
	Kimpak	30	20	28	—	—	67	1	—-
	—	—	—	13–60	55	7	64	15	92
U. crassifolia	Soil	32	21	80	56	78	56	2	—
U. glabra	Germinator or sand	21–30	20–25	30–60	—	—	44	72+	—
U. laevis	Germinator or sand	21	21	30	—	—	65	22+	85
U. parvifolia	Paper pads	20–29	20	10–60	—	—	55	2+	64
U. pumila	Paper pads	—	—	10	—	—	—	—	—
	Kimpak	30	20	28	—	—	81	1	—
	Germinator or sand	20–30	20	30	55	10	76	48	90
U. rubra	Sand	30	20	60	21	10	23	5	94
U. serotina	Soil	32	21	30	68	20	72	1	—
U. thomasii	Sand or petri dish	30	20	30	77	8	81	11	95

Sources: Arisumi and Harrison (1961), AOSA (2001), Engstrom and Stoeckeler (1941), Gorshenin (1941), Heit (1967a&, 1968), ISTA (1999), Johnson (1946), Kirby and Santelman (1964), Maisenhelder (1968), McDermott (1953), NBV (1946), Rafn and Son (1928), Rohmeder (1942), Spector (1956), Stoeckeler and Jones (1957), Sus (1925), Swingle (1939), USDA FS (2002), Wappes (1932).

* Light for 8 hours or more per day is recommended for American elm (AOSA 2001; ISTA 1999; McDermott 1953). Light is neither required nor inhibitory for germination of winged elm (Loiseau 1945), and Chinese and Siberian elms (AOSA 2001; ISTA 1999).

Table 7—*Ulmus*, elm: nursery practice

	Sowing	Seedlings/area		Sowing depth		Tree	Out-planting
Species	season*	/m²	/ft²	mm	in	percent	age (yrs)
U. alata	Summer	—	—	0–6.4	0–$^1/_4$	—	1
U. americana	Spring	5	2	6.4	$^1/_4$	12	1
U. crassifolia	Spring	—	—	0–6.4	0–$^1/_4$	—	1
U. glabra	Summer	—	—	0–6.4	0–$^1/_4$	—	—
U. laevis	Summer	—	—	0-6.4	0–$^1/_4$	6	1–2
U. parvifolia	Spring	25–30	2–3	4.8–6.4	$^3/_{16}$–$^1/_4$	12–20	1–2
U. pumila	Summer	—	—	6.4	$^1/_4$	3–7	1–2
U. rubra	Spring	25	2	6.4	$^1/_4$	—	1
U. serotina	Spring	—	—	0–6.4	0–$^1/_4$	—	1
U. thomasii	Spring	15–38	1–4	6.4	$^1/_4$	—	2

Sources: Baker (1969), Deasy (1954), Engstrom and Stoeckeler (1941), George (1937), Kirby and Santelman (1964), Rohmeder (1942), Stoeckeler and Jones (1957), Sus (1925), Swingle (1939), Toumey and Korstian (1942).
* Spring-sowing was preceded by stratification in sand or in a plastic bag at 4 to 5 °C for 60 days.

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Lauraceae—Laurel family

Umbellularia californica (Hook. & Arn.) Nutt.

California-laurel

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Growth habit, occurrence, and uses. The genus *Umbellularia* contains a single species—*Umbellularia californica* (Hook. & Arn.) Nutt.—that has many common names (Coombes 1992; Stein 1990), the best known being California-laurel, California-olive, Oregon-myrtle, myrtlewood, bay, laurel, and pepperwood. California-laurel is a broad-leaved evergreen that matures either as a shrub or tall forest tree. Over much of its range, it attains heights of 12 to 24 m and diameters of 46 to 76 cm, but near the ocean, in the chaparral, and on other severe or rocky sites it is confined to prostrate or shrub sizes (Harlow and others 1979; Jepson 1910). In the protected bottomlands of southern Oregon and northern California, mature trees are 91 to 305 cm in diameter and 30 or more m tall (Harlow and others 1979). A maximum circumference of 1,387 cm at 137 cm above ground (AFA 2000) and a maximum height of 53.3 m have been reported (Sargent 1961).

Several racial variations are recognized. *Umbellularia californica* forma *pendula* Rehd. is an uncommon, broad-spreading tree distinctive for its pendulous branchlets that contrast strongly with typically ascending branch growth (Jepson 1910; Rehder 1940). *U. californica* var. *fresnensis* Eastwood has fine white down on the lower surfaces of leaves and branches of the panicle (Eastwood 1945). Several forms that Jepson (1910) describes—gregarious, rockpile, dwarf, and prostrate—may indicate other varietal differences.

The range of California-laurel spans more than 11 degrees of latitude, from near the 44th parallel in the Umpqua River Valley of Douglas County, Oregon, south beyond the 33rd parallel in San Diego County, California, nearly to the Mexican border. California-laurel is widely distributed in the coast ranges and less abundantly in inland valleys and the Siskiyou and Sierra Mountains (Sudworth 1908). It may be found from sea level to 1,220 m in much of its range, and from 610 to 1,520 m in southern California (Jepson 1910). Pure, dense stands of California-laurel develop in some areas, but more often it is intermixed with other tree and shrub species. It grows in many kinds of soils under both cool-humid and hot-dry atmospheric conditions (Stein 1990). In xeric climates, it is most prominent where soil moisture is favorable—on alluvial deposits or protected slopes, along watercourses, near springs and seeps—but in its shrub form, it also is found on dry slopes and is a common component of chaparral (Sampson and Jespersen 1963).

All parts of the tree have served human needs. Wood of this species compares favorably in machining quality with the best eastern hardwoods (Davis 1947) and is used for woodenware, interior trim, furniture, paneling, veneer, and gunstocks. Burls and other growths with distorted grain are especially prized for making the gift and novelty items that are marketed extensively as "myrtlewood." Dried leaves are used for seasoning meats and soups (McMinn 1970). In an earlier day, Hudson Bay Company trappers brewed a comforting tea from the leaves to overcome chill (Ross 1966). David Douglas learned that hunters made a drink from the bark and declared it "by no means an unpalatable beverage" (Harvey 1947). Native Americans ate substantial quantities of the fruit and seeds, made a drink from the bark of the roots, and used the leaves for several internal and external medicinal purposes, including vermin control (Chesnut 1902).

Extracts of the leaves, seeds, and wood have strong chemical properties and should be used with caution. Vapor from the aromatic leaves can cause sneezing, headache, sinus irritation, other severe discomforts, and even unconsciousness (Drake and Stuhr 1935; Peattie 1953). The leaves contain considerable menthol (Stein 1974) and the ketone umbellulone, which when extracted from the leaf oil, interferes strongly enough with respiration, heartbeat, and blood circulation to cause death in laboratory animals (Drake and Stuhr 1935). Umbellulone also has fungicidal and germicidal properties (Drake and Stuhr 1935). Oils from the wood, leaves, and seeds have been sold for pharmaceutical purposes such as treating catarrh, nervous disorders, rheumatism, meningitis, intestinal colic, and dyspepsia (Peattie 1953; Sargent 1895; Stuhr 1933).

California-laurel is used to a moderate extent as an ornamental evergreen. It has thick, glossy, medium-to-dark green persistent leaves that turn orange or yellow before they drop individually and contrasting pale yellow flowers. The very dense aromatic foliage often shapes naturally into a pleasing, symmetrical, rounded crown. Since it was first cultivated in 1829 (Rehder 1940), it has demonstrated the ability to grow well far outside its natural range (Stein 1958). It can be grown as a decorative potted plant for lobbies and patios and will tolerate moderate pruning (Kasapligil and Talton 1973).

California-laurel also has wildlife values—young sprouts are choice browse in spring and summer. Year-long use is rated by Sampson and Jespersen (1963) as good to fair for deer (*Odocoileus* spp.) and fair to poor for cattle, sheep, and goats. Longhurst and others (1952) list it as a principal browse species for deer in the north coastal ranges of California. Silver gray-squirrels (*Sciurus griseus*), dusky-footed wood rats (*Neotoma fuscipes*), and Steller's jays (*Cyanocitta stelleri*) feed on the seeds extensively (Bailey 1936; Van Dersal 1938). Hogs eat both seeds and roots (Jepson 1910; Van Dersal 1938).

Flowering and fruiting. California-laurel flowers regularly and often profusely. The small, pale yellow, perfect flowers grow on short-stemmed umbels that originate from leaf axils or near the terminal bud (figure 1). Flower buds develop early; those for the following year become prominent as current-year fruits are maturing. Within its long north–south range, California-laurel has been reported to flower in all months from November to May, beginning before new leaves appear (Jepson 1910; Kasapligil and Talton 1973; Rehder 1940; Unsicker 1974). The flowering period may stretch into late spring and summer with the occasional appearance of flowers originating in axils of the current year's developing leaves (Sargent 1895). California-laurel flowers at an early age; flowers have been observed on short whiplike shrubs and on 1-year-old sucker growth that originated on a long broken stub. Small insects appear to be the chief pollinaters (Kasapligil 1951).

Seedcrops are abundant in most years (Stein 1974). Although umbels bear 4 to 9 flowers each, generally only 1 to 3 fruits set (Jepson 1910). The age when a tree first bears fruit, the age for maximum production, and the average quantity produced have not been reported. Seeds are produced in abundance after trees are 30 to 40 years old (Harlow and others 1979). Damage to developing seedcrops by insects, birds, or diseases has not been reported.

Collection, extraction, and storage. The fruits—acrid drupes each containing a single, large, thin-shelled seed—ripen in the first autumn after flowering (Rehder 1940; Sargent 1895; Sudworth 1908). As the drupes mature, their thin, fleshy hulls change from medium green to speckled yellow green (Britton 1908; Sudworth 1908) (figure 1), pale yellow (Eliot 1938), or various other hues, ranging from yellow-green tinged with dull red or purple (Peattie 1953; Sargent 1895) through purplish brown (Jepson 1910; Kasapligil 1951) to purple (Kellogg 1882; Sargent 1892; Torrey 1856). Ripe drupes may be yellow-green on one tree and dark purple on an adjacent tree (Stein 1974).

Drupes fall stemless to the ground in late autumn or winter and are dispersed by gravity, wind, animals, and water (McBride 1969). Seeds are collected simply by gathering fallen drupes—if squirrels and other animals don't get there first. Shaking ripe drupes from the tree should provide a good means for making quick, efficient collections.

When soft, the fleshy hulls are readily removed from the seeds by hand. The hulls can also be removed easily by machines used for de-pulping drupes if quantity processing is required. Mirov and Kraebel (1937) obtained about 300 cleaned seeds (figure 2) from 0.45 kg (1 lb) of drupes. For 8 samples processed at Davis, California (Lippitt 1995), the seed count averaged 547/kg (248/lb) and ranged from 403 to 675/kg (183 to 306/lb).

Figure 1—*Umbellularia californica*, California-laurel: yellow-green mature drupe suspended from its conical capula.

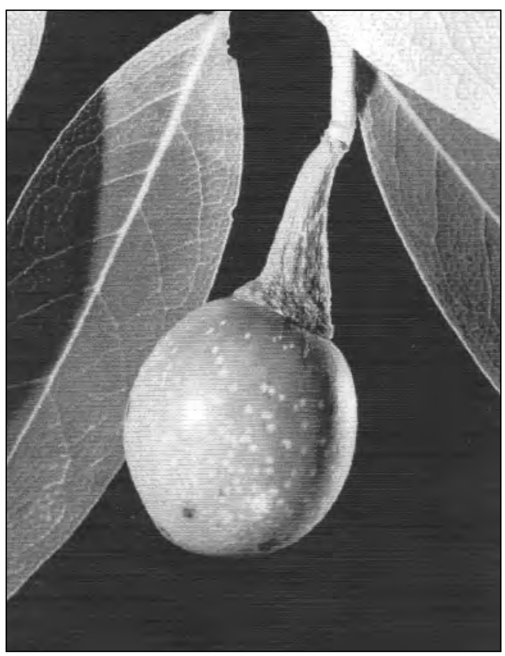


Figure 2—*Umbellularia californica*, California-laurel: exterior views of cleaned seeds.

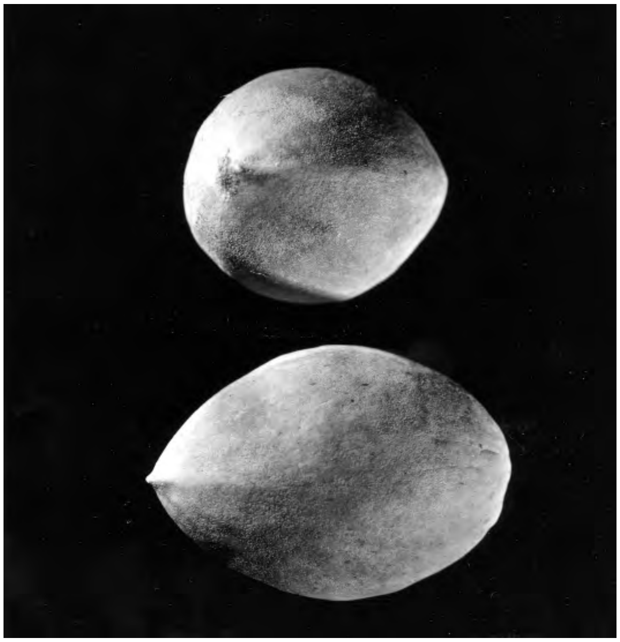
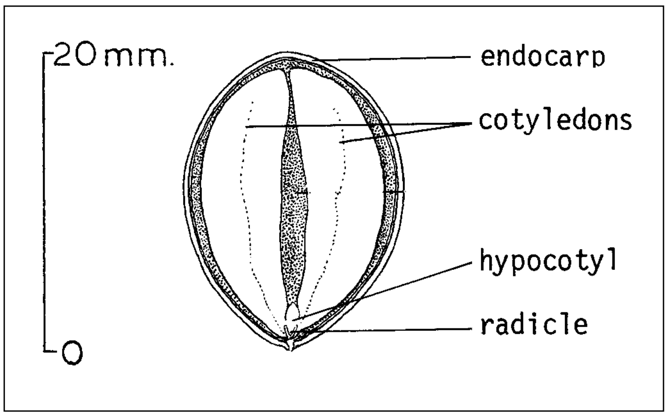


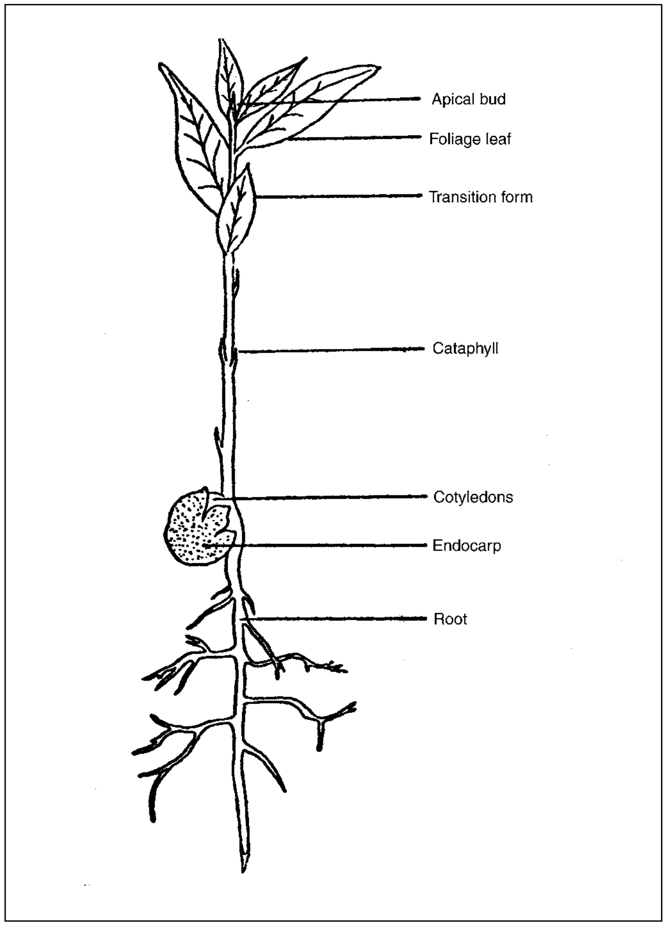
Figure 3—*Umbellularia californica*, California-laurel: tudinal section through a seed.



Seeds of California-laurel have lost viability in storage even at low temperatures, so yearly collection of fresh seeds is advised (Stein 1974). Viability has been maintained for 6 months when seeds were stored at 3 °C in wet, fungicide-treated vermiculite (McBride 1969). Storage trials have been very limited and tests of cool, moist storage at different moisture contents are needed. Highest germination (81%) was obtained from a seedlot with 32% moisture content (Lippitt 1995). Under favorable natural conditions, seeds on the ground retain their viability over winter, but under adverse conditions, viability may prove transient.

Seed treatment and germination. Fresh untreated seeds will germinate under room or outdoor conditions in peat moss, sawdust, vermiculite, or light-textured soil but may require 3 months or longer (Kasapligil 1951; Mirov and

Figure 4—*Umbellularia californica*, California-laurel: 4-month-old seedling (from Stein 1974, courtesy of Baki Kasapligil 1951).



Kraebel 1937; Stein 1974). Germination can be speeded by scarifying, cracking, or removing the endocarp or by stratifying the seeds, but it still may require about 2 months (Kasapligil 1951; McBride 1969; Stein 1974). In light soil, 20 to 25% of untreated seeds germinated; with stratification, germination nearly doubled (Stein 1974). In 16 lots of seeds collected in 1969 from Oregon and California sources, germination by the end of March ranged from 0 to 82% after January planting deep in pots of peat or vermiculite. Parts of seedlots held in a refrigerator at 4.4 °C from November to January germinated somewhat better than those immediately planted outdoors in a peat–vermiculite mixture. The better seedlots germinated equally well in several contrasting test conditions (Stein 1974).

In comparison tests made in petri dishes, California-laurel germination was highest in 30 days under a temperature regime of 16 °C day, 7 °C night, and when evaporative stress was minimal (McBride 1969). Germination did not appear affected by light level but was highest in soil with moisture tension at 4 to 10 atmospheres.

Seedling development and nursery practice. Under forest conditions, germination has been reported to take place in autumn soon after seedfall (Harlow and others 1979; Sargent 1895; Sudworth 1908) or in late winter and spring (Stein 1958, 1974). Covered seeds germinate best, but the large seeds do not bury readily without ground disturbance or silt deposition by high water. Seedling establishment is uncommon in the drier parts of California except in protected areas and where the ground is disturbed (Jepson 1910).

Germination is hypogeal, and the fleshy cotyledons remain within the endocarp and attached to the seedling until midsummer, when the plant may be 15 to 20 cm tall (Kasapligil 1951; Sargent 1895). Generally, there are 2 large cotyledons, sometimes 3, and no endosperm (figure 3) (Kasapligil 1951).

Young California-laurel seedlings appear flexible in their growth requirements. In the first 120 days, seedlings potted in vermiculite grew well at several levels of temperature, evaporative stress, soil moisture, and soil nutrients (McBride 1969). Seedlings grown at 18% or more of full sunlight produced the most dry weight. Seedlings produce leaves of several transitional forms as they develop (figure 4) and do not branch until they are 2 or 3 years old unless so induced by removal of the terminal bud (Kasapligil 1951). They soon develop a moderately stout taproot and are difficult to transplant if more than 1 year old unless grown in containers. Recovery after transplanting is often slow, and height growth may be limited for several seasons.

California-laurel may also be reproduced by cuttings (Stein 1974). Under field conditions, it sprouts prolifically from the root collar, stump, and fallen or standing trunk.

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Ericaceae—Heath family

Vaccinium L.

blueberry, cranberry

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Occurrence, growth habit, and uses. There are about 150 to 450 species (the number varies by authority) of deciduous or evergreen shrubs (rarely trees or vines) in *Vaccinium* (Huxley 1992b; LHBH 1976; Vander Kloet 1988). The majority of species are native to North and South America and eastern Asia (LHBH 1976; Vander Kloet 1988). Some of the more commonly cultivated North American species are listed in table 1. Like other members of the Ericaceae, *Vaccinium* species require an acidic (pH 4.0 to 5.2) soil that is moist, well drained, and high in organic matter (3 to 15%). Symptoms of mineral nutrient deficiency arise if soil pH exceeds optimum levels (LHBH 1976). Sparkleberry is one exception that grows well in more alkaline soils (Everett 1981). Many species of *Vaccinium* establish readily on soils that have been disturbed or exposed (Vander Kloet 1988).

Many species of *Vaccinium* are rhizomatous, thus forming multi-stemmed, rounded to upright shrubs or small trees ranging in height from 0.3 to 5.0 m (table 1). Cranberry forms a dense evergreen ground cover about 1 m in height (Huxley 1992b; Vander Kloet 1988).

Several species of *Vaccinium* are valued for their edible fruits. Historically, Native Americans consumed blueberries fresh or dried them for winter consumption (Vander Kloet 1988). In addition, they steeped the leaves, flowers, and rhizomes in hot water and used the tea to treat colic in infants, to induce labor, and as a diuretic (Vander Kloet 1988). Currently, most commercial blueberry production occurs in North America, where highbush blueberry accounts for more than two-thirds of the harvest (Huxley 1992a). Another species, rabbiteye blueberry, is more productive, heat resistant, drought resistant, and less sensitive to soil pH than highbush blueberry, but it is less cold hardy (Huxley 1992a; LHBH 1976). In more northern latitudes, the low-growing lowbush and Canadian blueberry bushes occur in natural stands. Their fruits are harvested for processing or the fresh fruit market (LHBH 1976).

Although cranberry has been introduced successfully into cultivation in British Columbia, Washington, and Oregon, Wisconsin and Massachusetts remain the largest producers; the crops for 2000 were estimated at 2.95 and 1.64 million barrels, respectively (NASS 2001).

Evergreen huckleberry grows along the Pacific Coast and is valued for its attractive foliage, which is often used in flower arrangements (Everett 1981). Species of *Vaccinium* also are prized as landscape plants. Lowbush forms are used to form attractive ground covers or shrubs. Two cultivars of creeping blueberry (*V. crassifolium* Andrews)—'Wells Delight' and 'Bloodstone'—form dense ground covers usually < 20 cm in height, varying only in texture and seasonal color change (Kirkman and Ballington 1985). Shrub-forming species add interest to the landscape with their attractive spring flowers and brilliantly colored fall foliage (Dirr 1990). Bird lovers also include *Vaccinium* spp. in their landscapes as the shrubs attract many birds when fruits ripen. In the wild, species of *Vaccinium* also serve as a source of food for many mammals (Vander Kloet 1988).

Geographic races and hybrids. Breeding programs have focused on improvement of species of *Vaccinium* since the early 20th century (Huxley 1992a). As a result, numerous hybrids and cultivars exist, each suited to specific growing conditions.

Flowering and fruiting. Perfect flowers are borne solitary or in racemes or clusters and are subterminal or axillary in origin (Vander Kloet 1988). White flowers, occasionally with a hint of pink, occur in spring or early summer, usually before full leaf development (table 2) (Dirr 1990). Rabbiteye and lowbush blueberries are generally self-sterile and must be interplanted to ensure fruit-set. Highbush blueberries are self-fertile, although yields can be improved by interplanting with different cultivars (Huxley 1992a). When mature, fruits of blueberries are many-seeded berries (figure 1), blue to black in color, often glaucous, ranging in size from 6.4 to 20 mm in diameter with a per-

Table 1—*Vaccinium,* blueberry and cranberry: nomenclature, plant height, and natural occurrence

Scientific name & synonym(s)	Common name(s)	Plant height (cm)	Occurrence
***V. angustifolium* Ait.** *V. lamarckii* Camp *V. nigrum* (Wood) Britt. *V. angustifolium* var. *hypolasium* Fern. var. *laevifolium* House var. *nigrum* (Wood) Dole var. *brittonii* Porter ex Bickn.	**lowbush blueberry,** late sweet blueberry, low sweet blueberry	18 ± 9	Labrador & Newfoundland; W to Manitoba & Minnesota; S to Illinois, Delaware, & Pennsylvania; mtns of Virginia & West Virginia
***V. arboreum* Marsh.** *V. arboreum* var. *glaucescens* (Greene) Sarg. *Batodendron andrachniforme* Small *Batodendron arboreum* (Marsh.) Nutt.	**sparkleberry,** farkleberry	311 ± 102	Virginia to central Florida, W to E Texas, central Oklahoma & SE Mississippi
***V. corymbosum* L.** *V. constablaei* Gray *V. corymbosum* var. *albiflorum* (Hook.) Fern. *V. corymbosum* var. *glabrum* Gray *Cyanococcus corymbosus* (L.) Rydb. *Cyanococcus cuthbertii* Small	**highbush blueberry,** American blueberry, swamp blueberry	230 ± 60	Atlantic Coast; W to E Texas & Illinois; absent from Mississippi, central Ohio, W Kentucky, W Tennessee, West Virginia, & central Pennsylvania
***V. macrocarpon* Ait.** *Oxycoccus macrocarpus* (Ait.) Pursh	**cranberry,** large cranberry, American cranberry	6 ± 3	Newfoundland, W to Minnesota, S to N Illinois, N Ohio, & central Indiana; Appalachian Mtns to Tennessee & North Carolina
***V. myrtilloides* Michx.** *V. angustifolium* var *myrtilloides* (Michx.) House *V. canadense* Kalm ex A. Rich. *Cyanococcus canadensis* (Kalm ex A. Rich) Rydb.	**Canadian blueberry,** velvet-leaf blueberry, velvetleaf huckleberry, sour-top blueberry	35 ± 14	Central Labrador to Vancouver Island, Northwest Territories SE to Appalachian Mtns
***V. ovatum* Pursh.**	**California huckleberry,** evergreen huckleberry, shot huckleberry	82 ± 42	Pacific Coast, British Columbia to California
***V. oxycoccos* L.** *V. palustre* Salisb. *Oxycoccus palustris* Pers. *Oxycoccus quadripetalus* Gilib.	**small cranberry**	2 ± 1	North American boreal zone to the Cascade Mtns in Oregon & to Virginia in the Appalachian Mtns
***V. virgatum* Ait.** *V. virgatum* var. *ozarkense* Ashe *V. virgatum* var. *speciosum* Palmer *V. parviflorum* Gray; *V. amoenum* Ait. *V. ashei* Rehd.; *V. corymbosum* var. *amoenum* (Ait.) Gray *Cyanococcus virgatus* (Ait.) Small *Cyanococcus amoenus* (Ait.) Small	**rabbiteye blueberry,** smallflower blueberry	300 ± 100	SE United States
***V. vitis-idaea* L.**	**lingonberry,** cowberry, foxberry, mountain cranberry	7 ± 3	New England & scattered throughout Canada; native to Scandinavia

Sources: GRIN (1998), Huxley (1992b), Vander Kloet (1988).

sistent calyx (table 3) (LHBH 1976). Cranberry fruits are many-seeded berries that are red at maturity and range from 1 to 2 cm in diameter (Huxley 1992b).

Collection of fruits, seed extraction, and cleaning. Small quantities of ripe fruits may be collected by hand-picking. Larger quantities, however, are usually harvested mechanically (Huxley 1992a). To extract seeds, fruits should be placed in a food blender, covered with water, and thoroughly macerated using several short (5-second) power bursts. More water is added to allow the pulp to float while the sound seeds (figures 2 and 3) settle to the bottom. Repeating this process several times may be necessary to achieve proper separation of seeds and pulp (Galletta and Ballington 1996). Seed weights are listed in table 3.

Table 2—*Vaccinium*, blueberry and cranberry: phenology of flowering and fruiting for cultivated species

Species	Flowering	Fruit ripening	Mature fruit color
V. angustifolium	May–June	July–Aug	Blue to black; glaucous
V. arboreum	May–June	Oct–Dec	Shiny black to glaucous blue
V. corymbosum	June	June–Aug	Dull black to blue & glaucous
V. macrocarpon	May–June	Sept–Oct	Red
V. myrtilloides	—	—	Blue & glaucous
V. ovatum	Mar–July	Aug–Sept	Blue & glaucous to dull black
V. virgatum	Mar–May	June–Aug	Black or glaucous blue
V. vitis-idaea	May–June	Aug	Red

Source: Ballington (1998), Crossley (1974), Dirr (1990), Vander Kloet (1988)

Figure 1—*Vaccinium*, blueberry: fruits (berries) of *V. angustifolium*, lowbush blueberry (**top**); *V. corymbosum*, highbush blueberry (**bottom**).

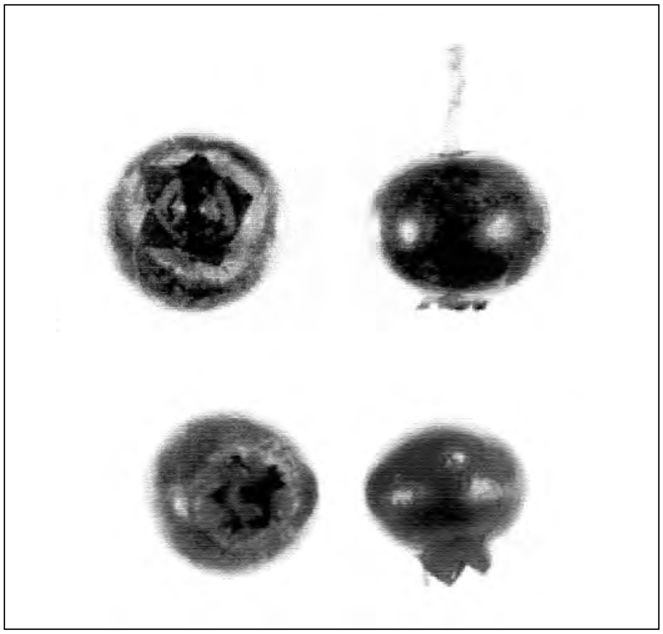


Table 3—*Vaccinium*, blueberry and cranberry: fruit and seed sizes of cultivated species

Species	Berry diameter (mm)	Cleaned seeds/weight /kg	Cleaned seeds/weight /lb
V. angustifolium	8 ± 1	3.90×10^6	1.45×10^6
V. arboreum	8 ± 1	1.01×10^6	4.59×10^5
V. corymbosum	8 ± 1	2.20×10^6	1.00×10^6
V. macrocarpon	12 ± 2	1.09×10^6	4.95×10^5
V. myrtilloides	7 ± 1	3.81×10^6	1.73×10^6
V. ovatum	7 ± 1	2.99×10^6	1.36×10^6
V. oxycoccos	9 ± 2	1.46×10^6	6.62×10^5
V. virgatum	12 ± 4	—	—
V. vitis-idaea	9 ± 1	3.54×10^4	1.61×10^4

Sources: Huxley (1992b), Vander Kloet (1988).

Seed storage. There have been no long-term studies of blueberry seed storage, but there is enough information to suggest that the seeds are orthodox in their storage behavior. Sparkleberry seeds, for example, still germinated after being buried in the soil for 4 years in Louisiana (Haywood 1994). Aalders and Hall (1975) investigated the effects of storage temperature and dry seed storage versus whole-berry storage of lowbush blueberry. Seeds extracted from fresh berries and sown immediately germinated with 80% success. However, seeds stored dry at room temperature exhibited poor germination. Seeds stored dry at –23, –2, or 1 °C germinated in higher percentages than those stored in berries (uncleaned) at the same temperatures. Germination was not significantly different among the temperatures for dry stored seeds, nor between dry and whole-berry storage at –23 °C. However, if storage temperature was maintained at –2 or 1 °C, dry storage proved preferable to whole-berry storage.

Pregermination treatments. It has been well established that seeds of various species of *Vaccinium* are photoblastic and require several hours of light daily for germination (Devlin and Karczmarczyk 1975, 1977; Giba and others 1993, 1995; Smagula and others 1980). Although much debated, it appears that seeds of some *Vaccinium* species do not require any pretreatment for satisfactory germination. Devlin and Karczmarczyk (1975) and Devlin and others (1976) demonstrated that cranberry seeds would germinate after 30 days of storage at room temperature if light requirements were fulfilled during germination. Aalders and Hall (1979) reported that seeds of lowbush blueberry will germinate readily if they are extracted from fresh fruit and sown immediately. The literature regarding pretreatments for highbush blueberry is not conclusive. However, cold requirements among the various species appear to be species-specific. Although seeds of many species will germinate if sown immediately after they are extracted from fresh fruit, a dry cold treatment of 3 to 5 °C for about 90 days may increase germination or become necessary if seeds are allowed to dry (Ballington 1998). Gibberellic acid (GA_3 or GA_{4+7}) treatment has been shown to promote germination. Although GA does not increase total germination, it reduces the hours of light necessary or in some instances overcomes the light requirement, thus stimulating early and uniform germination (Ballington 1998; Ballington and others 1976; Devlin and Karczmarczyk 1975; Giba and others 1993; Smagula and others 1980).

Germination tests. In studies to investigate the light requirement for seed germination of lowbush blueberry, Smagula and others (1980) found that seeds germinated in light exhibited an increase in both germination rate and cumulative germination in comparison to seeds germinated in darkness. Gibberellic acid treatment enhanced germination in the light as well as dark germination, with 1,000 ppm (0.1%) sufficient to overcome dark inhibition. Seed germination of highbush blueberry can be enhanced by GA_3 (Dweikat and Lyrene 1988). In 4 weeks, 4% germination of nontreated seeds was reported, whereas 50% germination of seeds treated with 900 ppm GA_3 (0.09%) was reported. Higher concentrations did not significantly affect germination. Ballington and others (1976) found that GA treatments did not influence the final germination percentage of seeds of 'Tifblue' rabbiteye blueberry. However, treatment of seeds with 100 (0.01%), 200 (0.02%), or 500 ppm (0.05%) GA_{4+7} resulted in seedlings that reached transplanting size 2 to 4 weeks earlier than did control or GA_3 treatments. The effects of GA treatment on seed germination of cranberry is similar. Devlin and Karczmarczyk (1977) found that cranberry seeds failed to germinate without light. However, seeds treated with 500 ppm GA showed 69% germination after 20 days in the dark following treatment. They also reported that, under low light conditions, GA stimulated early germination.

Aalders and others (1980) demonstrated that seed size may be an indication of seed viability in clones of lowbush blueberry. Seeds that passed through a screen with openings of 600 μm germinated poorly (1 to 14%), whereas seeds retained on that screen germinated in higher percentages (5 to 74%). In general, they reported that larger seeds germinated in higher percentages, although optimal size was clone specific.

Nursery practice and seedling care. Due to seedling variability, sexual propagation is normally restricted to breeding programs. Seeds $\geq$ 600 μm in diameter should be allowed to imbibe a solution of 200 to 1000 ppm (0.02 to 0.1%) GA before being sown on the surface of a suitable medium and placed under mist to prevent desiccation. Germination during periods of high temperature should be avoided if no GA treatment is applied, as Dweikat and Lyrene (1989) have suggested that high temperatures may inhibit germination. Seedlings should be transplanted to a site with ample moisture where an appropriate pH can be maintained. For field production, soil should contain high amounts of organic matter, and plants should be mulched with 10 to 15 cm of organic matter (Huxley 1992a).

Asexual propagation—by division and also by rooting softwood or hardwood stem cuttings—is widely practiced commercially for clonal propagation (Huxley 1992a). Lowbush blueberry can be propagated easily from rhizome cuttings 10 cm (4 in) in length taken in early spring or autumn (Dirr and Heuser 1987). However, the new shoots form flower buds almost exclusively, and the resulting plants develop slowly due to excessive flowering (Ballington 1998). Successful propagation of highbush and rabbiteye blueberry by means of softwood or hardwood cuttings has also been reported (Mainland 1993). A much easier species to root, cranberry can be propagated by stem cuttings taken any time during the year and treated with 1,000 ppm (0.1%) indolebutyric acid (IBA) (Dirr and Heuser 1987). Micropropagation procedures for various species of *Vaccinium* have also been reported (Brissette and others 1990; Dweikat and Lyrene 1988; Lyrene 1980; Wolfe and others 1983). These procedures involve rapid *in vitro* shoot multiplication followed by *ex vitro* rooting of microcuttings, utilizing standard stem cutting methods.

Figure 2—*Vaccinium*, blueberry: seeds of *V. angustifolium*, lowbush blueberry (**A**); *V. arboreum*, sparkleberry (**B**); *V. virgatum*, rabbiteye blueberry (**C**); *V. corymbosum*, highbush blueberry (**D**); *V. macrocarpon*, cranberry (**E**); *V. myrtilloides*, Canadian blueberry (**F**); and *V. ovatum*, California huckleberry (**G**).

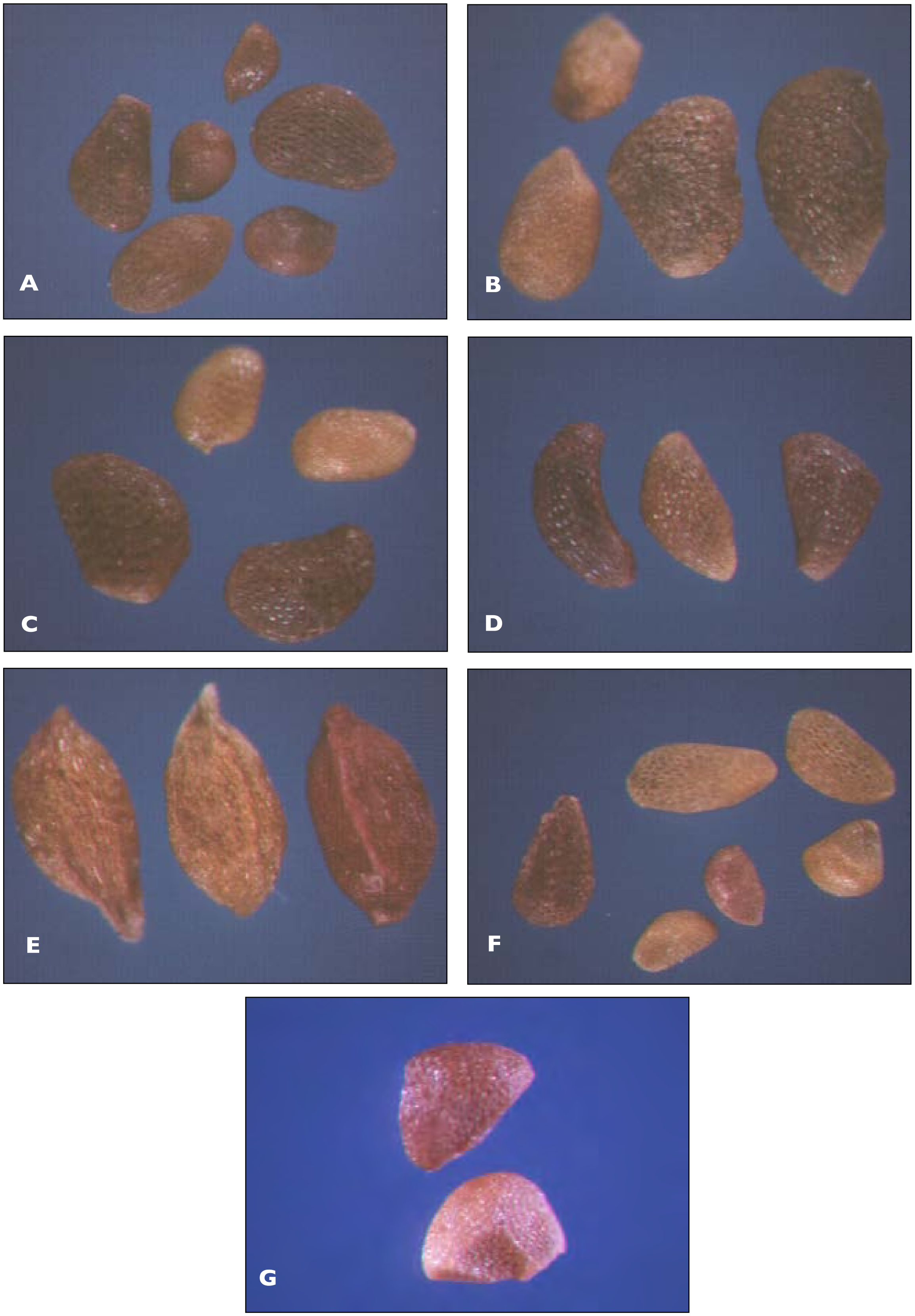
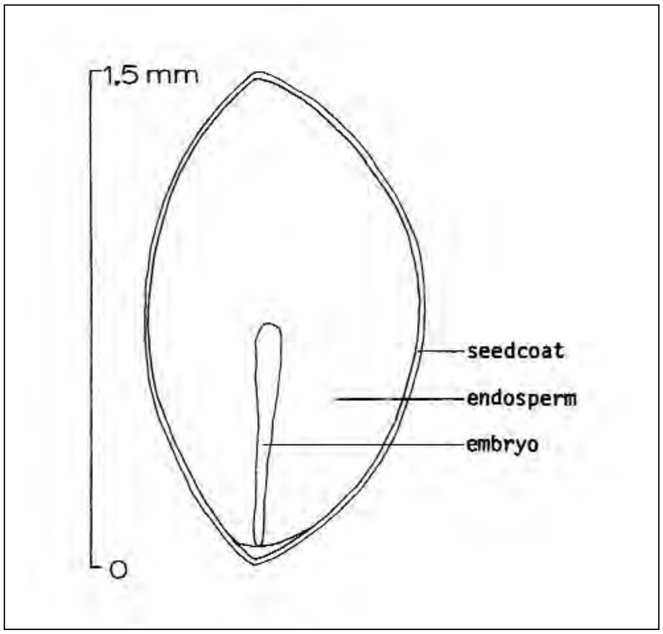


Figure 3—*Vaccinium corymbosum*, highbush blueberry: longitudial section of a seed.



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Euphorbiaceae—Spurge family

Vernicia fordii (Hemsl.) Airy-Shaw

tung-oil tree

Franklin T. Bonner

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Synonyms. *Aleurites fordii* Hemsl.

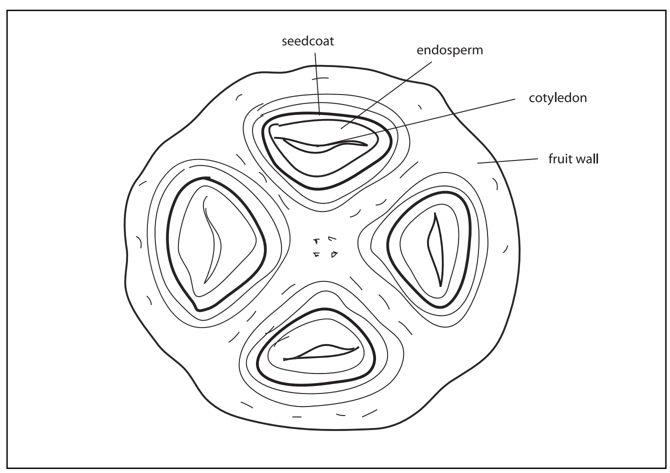
Occurrence and uses. Tung-oil tree—*Vernicia fordii* (Hemsl.) Airy-Shaw—is a native of central Asia. The species was introduced into the southern United States in 1905 as a source of tung oil (a component of paint, varnish, linoleum, oilcloth, and ink) that is extracted from the seeds. The use of this ingredient has declined in recent years in this country, but there are numerous research and breeding programs still underway in Asia. Extensive plantations were established along the Gulf Coast from Texas to Florida, and the tree has become naturalized (invasive) in some areas (Brown 1945; Brown and Kirkman 1990; Vines 1960). It has also been planted in Hawaii (Little 1979). Tung-oil tree is small, with a rounded top, and seldom reaches more than 10 m in height in the United States (Vines 1960).

Flowering and fruiting. Flowering is monoecious, but sometimes all staminate, or rarely all pistillate (Potter and Crane 1951). The white pistillate flowers with red, purple, or rarely yellow throats appear just before the leaves start to unfold in the spring. Borne in conspicuous, terminal cymes approximately 3.7 to 5 cm in diameter, the flowers create a showy display in large plantations. The fruits are 4-celled indehiscent drupes (figure 1), 3 to 7.5 cm in diameter, that ripen in September to early November (Bailey 1949; Potter and Crane 1951; Vines 1960). The seeds, 2 to 3 cm long and 1.3 to 2.5 cm wide, are enclosed in hard, bony endocarps (figures 2 and 3). They are sometimes referred to as stones or nuts. There may be 1 to 15 seeds per fruit, but the average is 4 to 5 (Potter and Crane 1951). The seeds are poisonous. Fruit production begins at about age 3, with commercial production by age 6 or 7 (Potter and Crane 1951). Good trees will yield 45 to 110 kg of seeds annually (Vines 1960).

Collection, cleaning, and storage. Fruits are shed intact in October or November (McCann 1942) and seeds may be collected from the ground. The fruit hulls should be removed as there is some evidence that hull fragments delay germination (Potter and Crane 1951). Cleaning is not a major problem. There are no definitive storage data for tung-oil tree seeds, but they are considered short-lived and are normally planted the spring following harvest. Their high oil content suggests that storage for long periods may be difficult.

Figure 1—*Vernicia fordii*, tung-oil tree: immature fruit (photo courtesy of Mississippi State University's Office of Agricultural Communications).

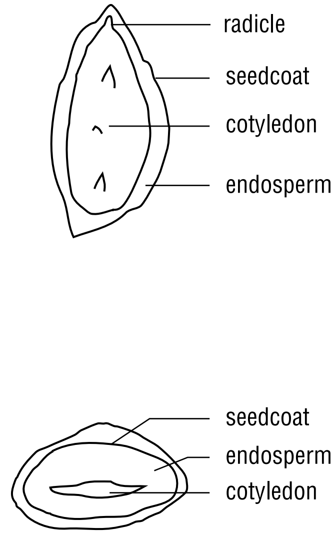
Figure 2—*Vernicia fordii*, tung-oil tree: cross-section of a fruit (adapted from McCann 1942).



Germination. No pretreatments are usually needed for germination. Seeds may be planted dry, or soaked in water for 2 to 5 days before sowing. The latter treatment is said to speed emergence (Potter and Crane 1951). Seeds typically germinate in 4 to 5 weeks (Vines 1960). Some growers have stratified seeds overwinter in moist sand at 7 °C (Potter and Crane 1951), but there does not appear to be much need for this treatment. There are no standard germination test prescriptions for this species.

Nursery practices. Seedling production of tung-oil tree is usually in row plantings instead of beds. Seeds should be planted 5 cm (2 in) deep, 15 to 20 cm (6 to 8 in) apart, in rows 1.5 m (5 ft) apart (Potter and Crane 1951). A good transplant size is 30 to 60 cm (1 to 2 ft). The tree can also be propagated vegetatively with hardwood cuttings (Vines 1960).

Figure 3—*Vernicia fordii*, tung-oil tree: longitudinal (**top**) and median (**bottom**) cross-sections of seeds.



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Caprifoliaceae—Honeysuckle family

Viburnum L.

viburnum

Franklin T. Bonner, John D. Gill, and Franz L. Pogge

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Growth habit, occurrence, and use. Among the 135 or so viburnum species, 12 that are either native to North America or have been introduced are discussed here (table 1). All 12 species are deciduous shrubs or small trees. Their characteristics place the viburnums among the most important genera for wildlife food and habitat and environmental forestry purposes. The attractive foliage, showy flowers, and fruits of viburnums have ensured their widespread use as ornamental plants as well. The fruits of most species are eaten by white-tailed deer (*Odocoileus virginianus*), rabbits (*Sylvilagus floridanus*), chipmunks (*Tamias striatus*), squirrels (*Sciurus* spp.), mice (*Reithrodontomys* spp.), skunks (*Mephitis mephitis*), ruffed grouse (*Bonasa umbellus*), ring-necked pheasants (*Phasianus colchicus*), turkeys (*Meleagris gallopavo*), and many species of songbirds. The twigs, bark, and leaves are eaten by deer, moose (*Alces americana*), rabbits, and beaver (*Castor canadensis*) (Martin and others 1951). The fruits of hobblebush, nannyberry, blackhaw, and

Table 1—*Viburnum*, viburnum: nomenclature and occurrence

Scientific name & synonym(s)	Common name(s)	Occurrence
***V. acerifolium* L.**	**mapleleaf viburnum,** dock-mackie, mapleleaf arrowwood, & Texas possum-haw	Minnesota to Quebec, S to Florida
***V. dentatum* L.** *V. pubescens* (Ait.) Pursh	**southern arrowwood,** roughish arrowwood, arrowwood viburnum	Massachusetts, S to Florida & E Texas
***V. lantana* L.**	**wayfaringtree,** wristwood, wayfaringtree virbunum	Native of Europe & W Asia; introduced from Connecticut to Ontario
***V. lantanoides* Michx.** *V. alnifolium* Marsh. *V. grandifolium* Ait.	**hobblebush**, hobblebush viburnum, moosewood, tangle legs, witch-hobble	Prince Edward Island to Michigan, S to Tennessee & Georgia
***V. lentago* L.**	**nannyberry,** blackhaw, sheepberry, sweet viburnum	Quebec to Saskatchewan, S to Missouri, Virginia, & New Jersey
***V. nudum* var. *nudum* L.** *V. cassinoides* L.	**possumhaw,** swamphaw	Coastal Plain, from Connecticut to Florida & Texas; N to Arkansas & Kentucky
***V. nudum* var. *cassinoides* (L.) Torr. & Gray**	**witherod viburnum,** wild-raisin, witherod	Newfoundland to Manitoba, S to Indiana, Maryland, & mtns of Alabama
***V. opulus* L** *V. opulus* var. *amerieanum* Ait. *V. trilobum* Marsh.	**European cranberrybush,** cranberrybush, Guelder rose, highbush-cranberry	Native of Europe; escaped from cultivation in N US & Canada
***V. prunifolium* L.**	**blackhaw,** stagbush, sweethaw	Connecticut to Michigan, S to Arkansas & South Carolina
***V. rafinesquianum* J. A. Schultes** *V. affine* Bush ex Schneid. *V. affine* var. *hypomalacum* Blake	**downy arrowwood,** Rafinesque viburnum	Manitoba to Quebec, S to Arkansas & Kentucky
***V. recognitum* Fern.**	**smooth arrowwood,** arrowwood	New Brunswick to Ontario, S to Ohio & South Carolina
***V. rufidulum* Raf.**	**rusty blackhaw,** southern blackhaw, bluehaw, blackhaw, southern nannyberry	Virginia to Kansas, S to E Texas & N Florida

Sources: Dirr and Heuser (1987), Little (1979), Vines (1960).

V

European cranberrybush are eaten by humans also (Gill and Pogge 1974). Medicinal uses have been found for fruits of European cranberrybush, blackhaw, hobblebush, and rusty blackhaw (Gould 1966; Krochmal and others 1969; Vines 1960). Most species prefer moist, well-drained soils, but drier soils are suitable for some, notably blackhaw, mapleleaf viburnum, and witherod viburnum. Soil texture and pH requirements are less critical than in most other genera; hobblebush, mapleleaf viburnum, and nannyberry are particularly tolerant of acidic soil (Rollins 1970; Spinner and Ostrum 1945). Most species are also shade tolerant, particularly hobblebush, mapleleaf viburnum, and the 3 arrowwoods (Gould 1966; Hottes 1939). The species that more typically thrive in the open or in partial shade include blackhaw, European cranberrybush, nannyberry, and witherod viburnum.

Flowering and fruiting. The small white, or sometimes pinkish, flowers are arranged in flattened, rounded, or convex cymes (figure 1). Flowers are typically perfect, but the marginal blossoms in hobblebush and European cranberrybush are sterile. In some cultivated varieties of European cranberrybush, all flowers may be sterile (Rollins 1970). Flowering and fruit ripening dates are mostly in May–June and September–October, respectively, but vary among species and localities (table 2). Pollination is primarily by insects (Miliczky and Osgood 1979). The fruit is a 1-seeded drupe 6 to 15 mm in length, with soft pulp and a thin stone (figures 2, 3, and 4). As viburnum drupes mature, their

Figure 1—*Viburnum lentago*, nannyberry: cluster of fruits (a compound cyme) typical of the genus.

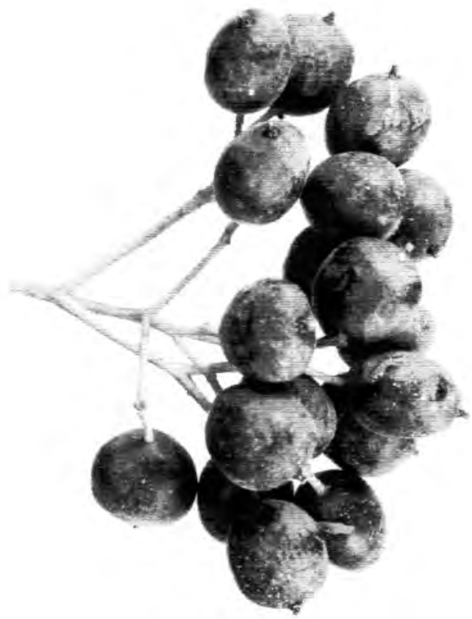


Table 2—*Viburnum,* viburnum: phenology of flowering and fruiting

Species	Location	Flowering	Fruit ripening	Seed dispersal
V. acerifolium	Midrange	May–Aug	July–Oct	Fall
	West Virginia	—	Late Oct	Nov–Dec
	South	Apr–May	Late July	Fall–Spring
V. dentatum	Midrange	May–June	Sept–Oct	to Dec
	Extremes	June–Aug	July–Nov	to Feb
V. lantana	Midrange	May–June	Aug–Sept	Sept–Feb
V. lantanoides	Midrange	May–June	Aug–Sept	Fall
	West Virginia	—	Late Sept	Oct–Nov
	New York	May	Aug–Sept	Aug–Oct
V. lentago	Midrange	May–June	Sept–Oct	Oct–May
	Extremes	Apr–June	Mid July	Fall–Spring
V. nudum var. *nudum*	South	Apr–June	Sept–Oct	—
V. nudum var. *cassinoides*	Midrange	June–July	Sept–Oct	Oct–Nov
	Extremes	May–July	July–Oct	—
V. opulus	Midrange	May–June	Aug–Sept	Mar–May
	Extremes	May–July	Sept–Oct	Oct–May
V. prunifolium	Midrange	Apr–May	Sept–Oct	to Mar
	Extremes	Apr–June	July–Aug	Oct–Apr
V. rafinesquianum	Midrange	June–July	Sept–Oct	Oct
	Extremes	May–June	July–Sept	—
V. recognitum	North	May–June	Aug–Sept	to Dec
	South	Apr–May	July–Aug	to Feb
V. rufidulum	South	Mar–Apr	Sept–Oct	Dec
	North	May–June	—	—

Sources: Brown and Kirkman (1990), Donoghue (1980), Gill and Pogge (1974).

Figure 2—*Viburnum*, viburnum: single fruits (drupes) of *V. nudum* var. *cassinoides*, witherod viburnum (**top left**); *V. lentago*, nannyberry (**top right**), *V. rafinesquianum*, downy arrowwood (**bottom left**); and *V. opulus*, cranberrybush (**bottom right**).

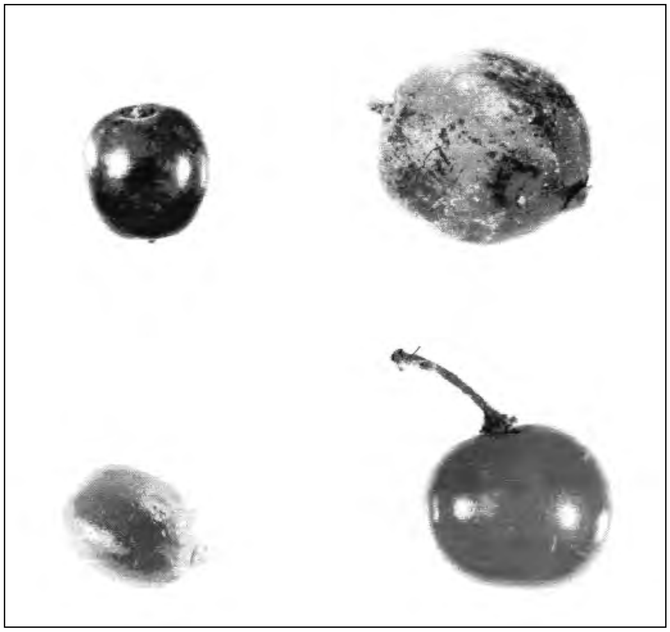
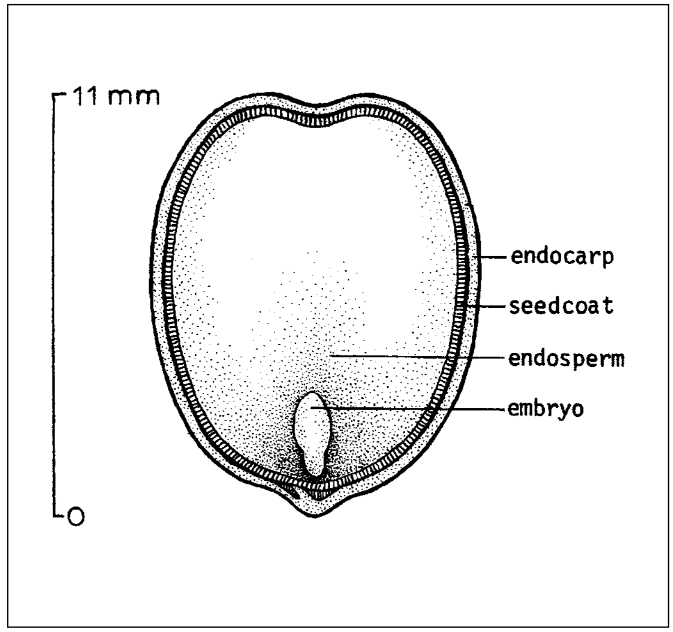


Figure 3—*Viburnum*, viburnum: cleaned seeds (stones) of (**top left to right**) *V. acerifolium*, mapleleaf viburnum; *V. lantanoides*, hobblebush; *V. nudum* var. *cassinoides*, witherod viburnum; *V. dentatum*, southern arrowwood; *V. lantana*, wayfaringtree; and (**bottom left to right**) *V. lentago*, nannyberry; *V. rafinesquianum*, downy arrowwood; *V. recognitum*, smooth arrowwood; *V. opulus*, European cranberrybush.

skins change in color from green to red to dark blue or black when fully ripe (Fernald 1950; Vines 1960). This color change is a reliable index of fruit maturity for most members of the genus in North America. The drupes of European cranberrybush, however, remain orange to scarlet when fully ripe (Fernald 1950). Age of viburnums at first fruiting varies among species, from 2 to 3 years up to 8 to 10 years (table 3). Production is usually meager in early

Figure 4—*Viburnum lentago*, nannyberry: longitudinal sections through a stone.



fruiting years, but most species produce fruit nearly every year. Species such as mapleleaf viburnum and hobblebush that grow in deep shade seldom produce large crops (Gould 1966). Much of the wildlife-habitat and ornamental value in viburnums is due to persistence of their fruits through winter (table 2). Dispersal is accomplished by animals or gravity.

Collection, extraction, and storage. The drupes may be hand-picked when their color indicates full physiological maturity (dark blue or black). After collection, care must be taken to prevent overheating as with all fleshy drupes. If whole drupes are to be sown, they should be spread out to dry before storage. If seeds are to be extracted, drying should be minimized to prevent toughening of the drupe coats. Extraction is recommended because there are good indications that cleaned seeds show higher levels of germination (Smith 1952). Extraction can be easily accomplished by maceration with water. Because good seeds should sink in water, the pulp can be floated off. An alternative method is to wash the pulp through screens with hoses. The seeds should then be dried for storage. Viburnum seeds are orthodox in storage behavior. Viability of air-dried seeds was maintained for 10 years by storage in a sealed container at 1 to 4 °C (Heit 1967). Whole fruits can be stored similarly (Chadwick 1935; Giersbach 1937). Average seed weight data are listed in table 4. Soundness in seed lots of several species has ranged from 90 to 96% (Gill and Pogge 1974).

Germination. Seeds of most viburnum species are difficult to germinate. The only official testing recommendation for any viburnum is to use tetrazolium staining (ISTA

Table 3—*Viburnum,* viburnum: growth habit, height, seed-bearing age, and seedcrop frequency

Species	Growth habit	Height at maturity (m)	Year first cultivated	Seed-bearing age (yrs)	Years between large seedcrops
V. acerifolium	Erect shrub	2	1736	2–3	1
V. dentatum	Erect shrub	5	1736	3–4	—
V. lantana	Shrub or tree	5	—	—	—
V. lantanoides	Erect or trailing shrub	3	1820	—	3 or 4
V. lentago	Shrub of tree	10	1761	8	1
V. nudum var. *nudum*	Shrub or tree	1.8	—	—	—
V. nudum var. *cassinoides*	Erect shrub	3	1761	—	1
V. opulus	Erect shrub	4	—	3–5	—
V. prunifolium	Shrub or tree	5	1727	8–10	1
V. rafinesquianum	Shrub	2	1830	—	—
V. recognitum	Erect shrub	3	—	5–6	—
V. rufidulum	Shrub or tree	3.5	—	5	—

Source: Gill and Pogge (1974).

Table 4—*Viburnum,* viburnum: fruit and seed weight and yield data

	Dried fruits/wt		Cleaned seeds/weight				
			Range		Average		
Species	/kg	/lb	/kg	/lb	/kg	/lb	Samples
V. acerifolium	10,600	4,800	24,050–36,600	10,900–16,600	28,000	13,100	5
V. dentatum	—	—	32,200–71,900	14,600–32,600	45,000	20,400	6
V. lantana	—	—	9,250–29,100	4,200–13,200	19,200	8,700	2
V. lantanoides	16,700	7,580	—	—	25,350	11,500	11
V. lentago	4,850	2,200	4,850–27,350	2,200–12,400	13,000	5,900	21
V. nudum var. *cassinoides*	6,600	3,000	55,100–63,950	25,000–29,000	60,850	27,6003	
V. opulus	12,100	5,500	20,700–39,250	9,400–17,800	30,000	13,600	12
V. prunifolium	—	—	8,800–13,230	4,000–6,000	10,600	4,800	5
V. rufidulum	5,200	2,360	—	—	—	—	—

Source: Gill and Pogge (1974).

1993). Most species have an apparent embryo dormancy and some have impermeable seedcoats as well (Gill and Pogge 1974). Dormancy in seeds of southern species is more readily overcome than in seeds of northern species. Seeds of the more northern forms need warm stratification for development of the radicle, followed by cold stratification to break dormancy in the epicotyl (shoot). European cranberrybush germinated 97% after 14 weeks of alternating temperatures between 20 and 2 °C (Fedec and Knowles 1973). For this reason, seeds of northern species seldom germinate naturally until the second spring after they ripen. In contrast, seeds of some southern viburnums usually complete natural germination in the first spring after seedfall. They ordinarily do not exhibit epicotyl dormancy and do not require cold stratification. Among the 12 species discussed here, only possumhaw and southern arrowwood from the southern part of its range may not need cold stratification (table 5 and figure 5) (Barton 1951; Giersbach 1937). Scarification of seeds has not improved germination (Barton 1958). Germination tests of stratified seeds have been made in sand or soil, but modern procedures would use moist paper blotters. The commonly suggested temperatures are alternating from 20 °C (night) to 30 °C (day) (table 5), but European cranberrybush is reported to germinate well at a constant 20 °C (Fedec and Knowles 1973).

Nursery practice. The warm-cold stratification sequence (table 5) can be accomplished in nurserybeds. Seeds or intact drupes can be sown in the spring, to allow a full summer for root development (figure 6). The ensuing winter temperatures will provide the cold stratification needed to break epicotyl dormancy. The principal advantage of this method, compared to stratification in flats or trays, is

Table 5—*Viburnum,* viburnum: stratification treatments and germination test results

	Stratification treatments (days)			Germination percentage	
	Warm period* (first stage)	Cold period† (second stage)	Germination test duration‡	Avg (%)	Samples
V. acerifolium	180–510	60–120	60+	32	5
V. dentatum§	0	0	60	—	—
V. lantanoides	150	75	100	43	3
V. lentago	150–270	60–120	120	51	3
V. nudum var. *cassinoides*	60	90	120	67	2
V. opulus	60–90	30–60	60	60	3+
V. prunifolium	150–270	30–60	60+	75	2
V. rafinesquianum	360–510	60–120	—	—	—
V. recognitum	360–510	75	60+	69	2
V. rufidulum	180–360	0	—	—	—

Sources: Gill and Pogge (1974), Vines (1960).
* Seeds in a moist medium were exposed to diurnally alternating temperatures of 30/20 °C or 30/10 °C, but a constant 20 °C was equally effective for most species (Barton 1958).
† Seeds and medium were exposed to constant temperature of 5 or 10 °C. Temperatures of 1to 6 °C are preferred now for cold stratification.
‡ At temperatures alternating diurnally from 30 (day) to 20 °C (night).
§ Seeds were collected in Texas; temperature was not critical for germination (Giersbach 1937).

Figure 5—*Viburnum dentatum*, southern arrowwood: seedling development at 1, 2, 11, and 29 days after germination; roots and shoots develop concurrently.

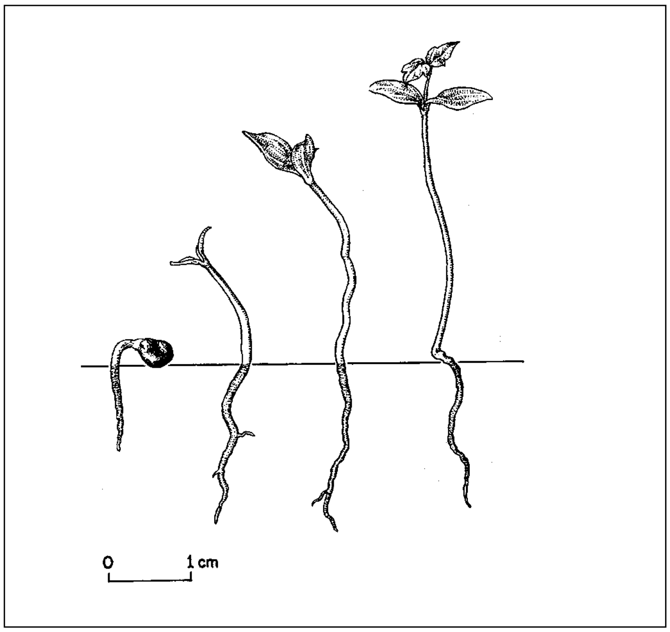
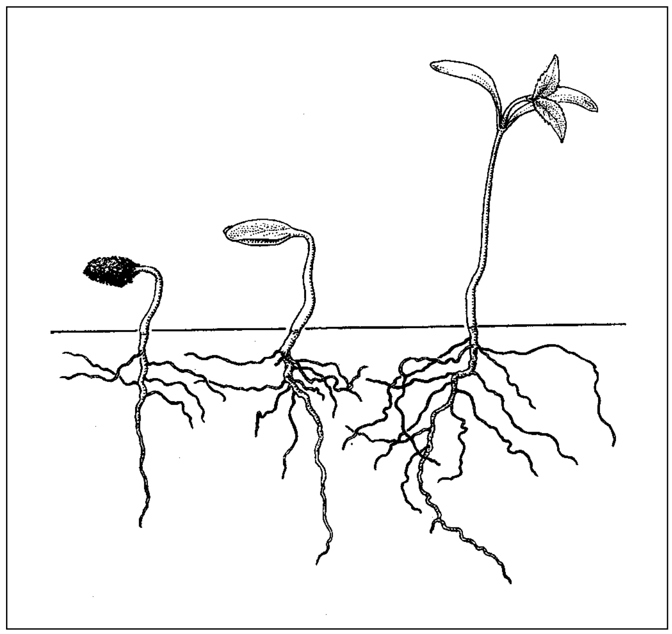


Figure 6—*Viburnum lentago*, nannyberry: seedling development from stratified seed—root development during warm stratification (about 150 days) (**left**); very little development during ensuing cold stratification (about 120 days) for breaking epicotyl dormancy (**middle**); subsequent development at germinating temperatures (**right**).



that seeds need not be handled after their roots emerge during the warm stratification period (Rollins 1970). Seeds of species with more shallow dormancy can be sown in the fall shortly after collection and extraction. For the several species that may be handled in this manner, the latest sowing dates for optimum seedling percentages in the ensuing year are listed in table 6. Sowing done somewhat earlier than these dates gave nearly as good results, but sowing at later dates reduced germination percentages.

The seeds may be broadcast on prepared seedbeds and mulched with sawdust (Rollins 1970). Alternatively, seeds can be sown in drills 20 to 30 cm (8 to 12 in) apart, covered with 12 mm ($^1/_2$ in) of soil, and mulched with straw (Gill and Pogge 1974). Straw mulch must be removed once germination begins, otherwise there is risk of loss due to damp-

Table 6—*Viburnum,* viburnum: latest allowable dates for sowing in nurserybeds and seedling percentages obtained in the following year

Species	Location	Latest allowable sowing date*	Seedling %†
V. acerifolium	New York	May 1	55
V. lantana	Ohio	Oct 21	90
V. lentago	Ohio	Oct 7	75
V. opulus	New York	July 1	87
V. prunifolium	New York	May 1	26
V. recognitum	New York	May 1	32

Sources: Giersbach (1937), Smith (1952).
* Sowing dates later than those listed resulted in reduced seedling percentages.
† Number of seedlings in a nurserybed at time of lifting expressed as a percentage of the number of viable seeds sown.

ing-off fungi. The recommended seedbed density for several viburnums is 215/m² (20/ft²) (Edminster 1947). Seedlings of some species may require shade for best development, although this depends on location and species. The most likely candidates for shading are the arrowwoods, hobblebush (Gould 1966), and mapleleaf viburnum. Seedlings should be ready for outplanting as 1+0 or 2+0 stock. A variety of techniques exist for rooting viburnum species by softwood cuttings, hardwood cuttings, or layering (Dirr and Heuser 1987).

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Verbenaceae—Verbena family

Vitex agnus-castus L.

lilac chastetree

John C. Zasada and C. S. Schopmeyer

Dr. Zasada retired from the USDA Forest Service's North Central Research Station; Dr. Schopmeyer (deceased) retired from the USDA Forest Service's National Office, Washington, DC

Other common names. chaste-tree, monks'-pepper tree, hemptree (Bailey 1949).

Growth habit, occurrence, and use. The genus *Vitex* occurs in both hemispheres in the tropical and subtropical zones. About 380 taxa have been described (Bredenkamp and Botha 1993). Lilac chastetree, a deciduous, strongly aromatic shrub or small tree, is one of the few species in the genus that is native to the temperate zones, but it is not native to North America (Bailey 1949). It has, however, naturalized in much of the southeastern United States.

In Washington on the west side of the Cascades, it attains a height of 1.8 m, increasing in more southerly latitudes to a height of 7.7 m in the low desert of southern California (Williamson 1967). Multiple stems support a broad spreading form, but shade trees with a single stem can be developed by pruning (Williamson 1967).

In the eastern United States, the species is hardy as far north as New York (USDA Hardiness Zone 6), but marginally so; it performs better further south, in USDA Hardiness Zones 8–9 (LHBH 1076; Dirr 1990; Moldenke 1968). This species is less hardy than negundo chastetree (*Vitex negundo* L.), which is also planted as an ornamental (Dirr 1990) and has been cultivated as an ornamental in southern Europe, the Middle East, India, and Brazil (Moldenke 1968). Lilac chastetree was introduced as an ornamental into the United States in 1570 (Rehder 1940). The species has value in shelterbelt plantings (Engstrom and Stoeckeler 1941).

Since the days of Dioscorides in the first century AD, seeds of this species have been noted for their ability to subdue sexual urges in men, hence the name "chastetree" (Moldenke 1968; Polunin and Huxley 1966). This property was recognized as being useful to celibates and this in turn led to the name "monks'-peppertree." However, these properties are questioned today. There is evidence that phytomedicines from the chastetree are useful in the treatment of menstrual disorders in women (Bohnert and Hahn 1990). Because of the aromatic pungency of fresh seeds, however, some people have considered the seeds as having aphrodisiac properties.

Other species (for example, negundo chastetree) are used in tropical and subtropical regions for biomass and fuelwood production because of their rapid growth, ability to coppice, and tolerance of a wide range of site conditions (Verma and Misra 1989).

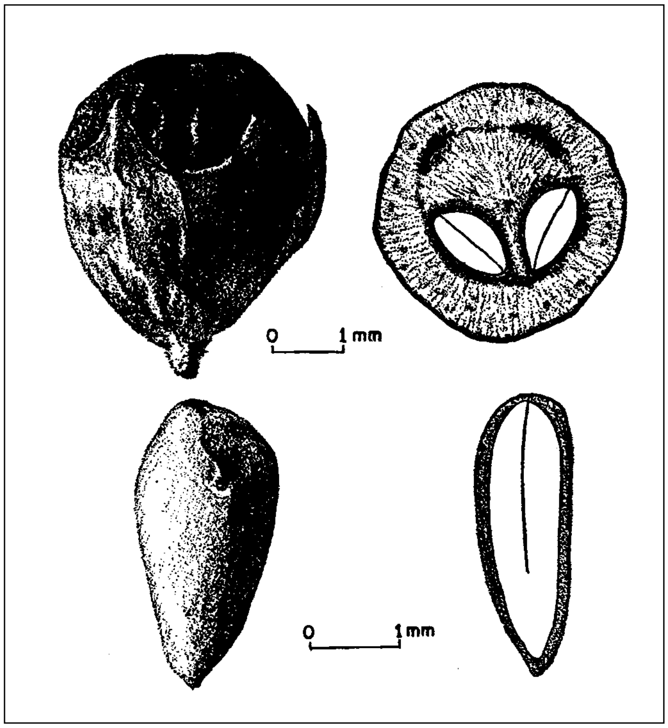
Varieties. Typical plants of the species have lavender flowers, but several other varieties have been cultivated in the United States (Rehder 1940; Dirr 1990). White chastetree, var. *alba* West., has white flowers. Hardy lilac chastetree, var. *latifolia* (Mill.) Loud., is characterized by broader leaflets and greater cold-hardiness. In addition, a form with pink flowers, f. *rosea* Rehder, has been propagated (Dirr 1990; Rehder 1940).

Flowering and fruiting. The fragrant flowers occur in dense spikes about 2.8 cm long; they bloom during the late summer and autumn in the United States (Bailey 1949). In Europe, flowering occurs from June to September (Moldenke 1968; Polunin and Huxley 1966). According to Dirr (1990), the plants will continue to flower as long as new growth is occurring; removing old flowers (deadheading) can prolong flowering.

The pungent fruits are small drupes about 3 to 4 mm in diameter that ripen in late summer and fall (Schopmeyer 1974). Good seedcrops occur almost every year (Engstrom and Stoeckeler 1941). Each drupe contains a rounded 4-celled stone about 3 mm long that is brownish to purple-brown and frequently partially covered with a lighter colored membranous cap. Each stone may contain from 1 to 4 seeds (figure 1) (Schopmeyer 1974).

Collection of fruits; extraction and storage of seeds. The fruits may be gathered in late summer or early fall by picking them from the shrubs by hand or by flailing or stripping them onto canvas or plastic sheets. Seeds can be removed by running the fruits dry through a macerator and fanning to remove impurities (Engstrom and Stoeckeler 1941). Seed weight per fruit weight is about 34 kg of

Figure 1—*Vitex agnus-castus*, lilac chastetree: fruit (**top left**) and transverse section through 2 seeds within a fruit (**top right**); cleaned seed (**bottom left**) and longitudinal section through a seed, with embryo taking up entire seed cavity (**bottom right**)



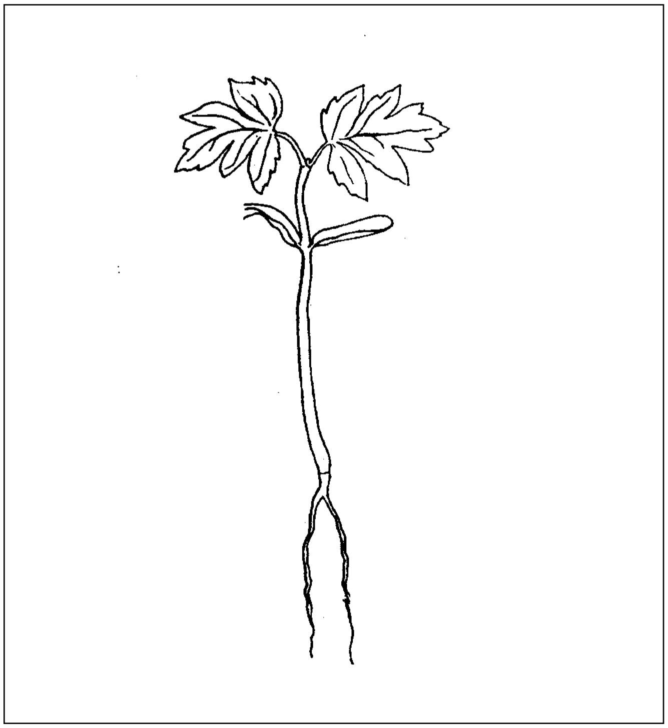
cleaned seed/45 kg of ripe fruit (75 lb/100 lb). Number of cleaned seeds varied from 74,800 to 130,000/kg (34,000 to 59,000/lb) in 4 samples (Schopmeyer 1974). Purity in 2 samples was 80%, and average soundness in 4 samples was 55%. In one test, seeds stored in moist sand and peat at 5 °C or 1 year showed no loss of viability (Schopmeyer 1974).

Germination. Seeds germinate readily without pretreatment (Dirr and Heuser 1987). However, stored seeds may exhibit dormancy that can be overcome by stratification in moist sand and peat for 90 days at about 5 °C. Germination tests should be made in sand flats for 40 days at 21 °C (night) to 30 °C (day) (Schopmeyer 1974). Germinative energy of stratified seeds was 18 to 60% in 10 to 22 days (3 tests). Germinative capacity of untreated seeds was 0.4% in 71 days (1 test); with stratified seeds, 20 to 72% (3 tests) (Schopmeyer 1974).

In another test, fresh seeds collected in January in southern California were sown without treatment in February in a greenhouse in Iowa. Germination was completed (percentage not stated) by April 20 when seedlings were 2 inches tall (King 1932). Germination is epigeal (King 1932) (figure 2).

Nursery practice. Stratified seeds of lilac chastetree should be sown in the spring and covered with 6 mm ($^1/_4$ in) of soil. On the average, about 16% of the viable seeds sown produce usable 2+0 seedlings (Engstrom and Stoeckeler 1941). Lilac chastetree can be readily propagated by greenwood cuttings collected before flowering, by hardwood cuttings in the fall, and layering (LHBH 1976; Dirr and Heuser 1987).

Figure 2—*Vitex agnus-castus*, lilac chastetree: seedling showing cotyledons and first leaves (from drawing by King 1932, used in 1948 edition).



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Vitaceae—Grape family

Vitis labrusca L.

fox grape

Franklin T. Bonner

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Other common names. northern fox grape, plum grape, northern muscadine, swamp grape, wild vine.

Growth habit, occurrence, and use. Fox grape—*Vitis labrusca* L.—a deciduous, woody vine, grows naturally from New England to Illinois and south to Georgia and infrequently, Arkansas (Vines 1960). It may climb on trees to a height of 12 m. Fox grape hybridizes readily with other *Vitis* species, and it has been the most important grape in the development of North American viticulture (Vines 1960), notably the 'Concord' varieties (Cawthon and Morris 1982). The fruits are important as food for many birds and mammals.

Flowering and fruiting. The dioecious flowers are both borne in short panicles, 5 to 10 cm long, in May or June. The fruit clusters usually have fewer than 20 globose berries, 8 to 25 mm in diameter. The berries mature in August to October and drop singly. Mature berries are brownish purple to dull black and contain 2 to 6 brownish, angled seeds that are 5 to 8 mm long (Vines 1960) (figures 1 and 2). Seed maturity is indicated by a dark brown seedcoat (Cawthon and Morris 1982).

Collection, extraction, and storage of seeds. Ripe berries can be stripped from the vines by hand or shaken onto canvas sheets. The seeds can be extracted by placing the berries in screen bags with 1.4-mm openings (approximately 14-mesh) and directing a solid stream of water at about 181 kg (400 lb) of pressure onto them. This removes the skins and pulp, most of which will be washed through the screen. The remaining fragments can be washed off in a pail of water. Seeds can also be extracted by running berries through a macerator or hammermill with water and washing the pulp away (Bonner and Crossley 1974). Six samples of fox grape seeds ranged from 32,900 to 34,000/kg (14,920 to

Figure 1—*Vitis labrusca*, fox grape: seed.

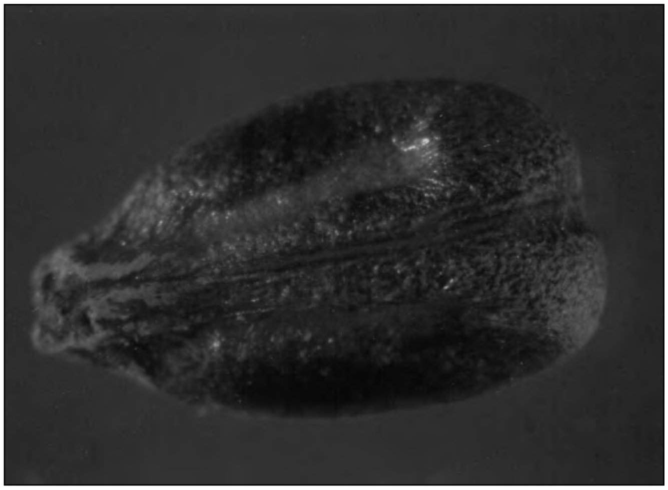
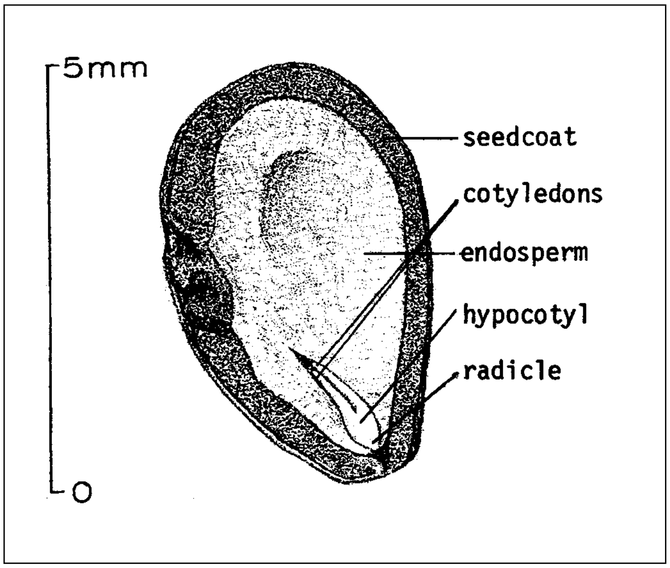


Figure 2 —*Vitis labrusca*, fox grape: longitudinal section through a seed.



15,430/lb) at a moisture content of 10%; the average was 34,600 seeds (15,070/lb). No storage data are available for fox grape, but other *Vitis* species have been stored successfully at low moisture contents at 5 °C in sealed containers (Bonner and Crossley 1974; Vories 1981). These results suggest that fox grape seeds are orthodox in storage behavior and can be stored successfully for at least several years.

Pregermination treatments. Fox grape seeds exhibit dormancy that can be overcome by moist stratification at 2 to 5 °C for several months. There are no specific data for fox grape, but a similar wild species—riverbank grape, *V. vulpina* L.—requires 90 days of stratification for germination testing (AOSA 1993) and up to 4 months has been recommended for spring planting in nurseries (Vories 1981). Soaking stratified seeds in solutions of nutrients or growth substances for 12 hours before sowing has also been reported as helpful in Europe (Simonov 1963).

Nursery practice. Seedlings rarely run true to type; hence, propagation by cuttings is common (Vines 1960).

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Arecaceae—Palm family

Washingtonia filifera (L. Linden) H. Wendl.

California washingtonia

Stanley L. Krugman

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Synonyms. *Washingtonia filamentosa* (Frenzi) Kuntze, *Neowashingtonia filimentosa (*Frenzi) Sudworth.

Other common names. California Washington-palm, desert-palm, California fan-palm, California-palm.

Growth habit, occurrence, and use. The California washingtonia—the only palm native to California—is the largest of the native palms in the United States (Bomhard 1950). Its sturdy, massive, cylindrical trunk grows to a height of 18 to 23 m and tapers very gradually from a diameter of 51 to 91 cm at the base to slightly less at the top. It has a broad open crown with as many as 50 fan-shaped, much-folded leaves with petioles as long as 1.5 m. Dead leaves may remain on the trunk for many years, forming a dense, thatch-like shroud or skirt about the trunk down to within a few feet of the ground (Sudworth 1908). This species is native to rocky streambeds and edges of other sources of water bordering the Colorado Desert in southeastern California and in Yuma County, Arizona, and northern Baja California, Mexico (Bomhard 1950). It is now widely planted in southern California, Arizona, Texas, and along the Gulf Coast for ornamental and environmental forestry purposes along roads or in small stands.

Geographic races. Studies employing electrophoretic techniques suggest that the current populations in southern California are either relicts or recent recolonizations from seed dispersal from a refugium population in Baja California, Mexico (McClenaghan and Beauchamp 1986).

Flowering and fruiting. In August, small but showy clusters of white, vase-shaped flowers are borne, enclosed initially by a spathe (Jepsen 1910). The mature flower stalk may average 3.7 m in length and extend almost horizontally in the crown (Bomhard 1950). The flowers are perfect and occur annually in great abundance once the tree reaches reproductive maturity. The calyx is tubular and the corolla is funnel-shaped, with the stamens inserted in its tube (Jepsen 1910).

The fruit and seeds mature during December and January. The ripe fruit is a spherical or elongated black berry about 10 to 13 mm long, with thin flesh surrounding a single hemispherical seed (DeMason 1988; Jepsen 1910; Sudworth 1908). The seeds are pale chestnut in color and measure about 6 to 8 mm long by 3 mm thick (figure 1); there are about 2,300 to 2,700 seeds/kg (1,040 to 1,225/lb) (Sudworth 1908). They are flattened somewhat on the ventral side (figure 2). The lance-shaped embryo is located on the round side of the seed near the raphe (DeMason 1988). There is a large cotyledon, an epicotyl, a small root apex, a horny endosperm, and a thin seedcoat (DeMason 1988; Jepsen 1910). The seeds are mature at the time of fruit drop.

Extraction and storage of seeds. The fleshy covering on the seeds should by removed in a macerator. The cleaned seeds then may be stored or sown immediately. Seeds should not be permitted to dry out (DeLeon 1958). Seeds of this species have been stored successfully in sealed containers at 5 °C for up to 6 years (Quick 1968), but long-term storage is not recommended.

Figure 1—*Washingtonia filifera*, California washingtonia: seed.

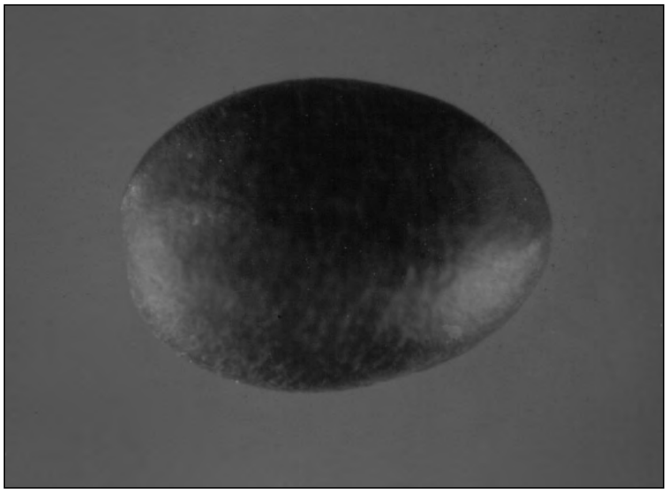
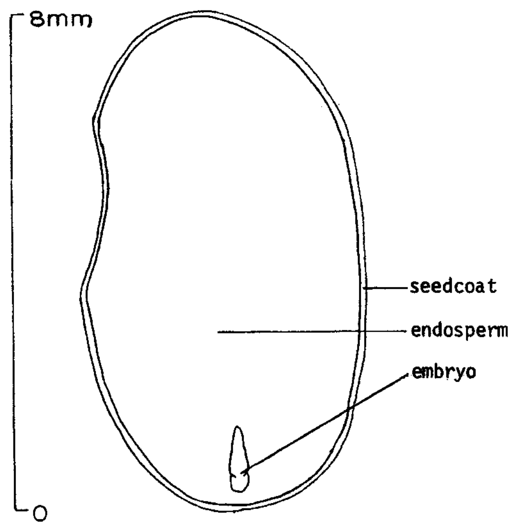


Figure 2—*Washingtonia filifera*, California washingtonia: longitudinal section through the embryo of a seed.



Germination and nursery practice. Fresh seeds with no treatment before sowing have germinated between 80 and 100% in 4 to 15 weeks (Emery 1969; McCurrach 1960). Seeds stored as long as 5 years also germinated well (87%) without a pretreatment. However, the time to reach maximum germination was reduced when stored seeds were stratified at 5 °C for 12 weeks before sowing (Quick 1968). Fresh or stratified seeds can be sown directly in a well-drained seedbed outdoors or in flats or other containers. Many growers prefer to sow the seed in a mixture of peat moss and sand or in just sand. Depth of cover has been 6 to 13 mm ($^1/_4$ to $^1/_2$ in), or a depth equivalent to the thickness of the seed (McCurrach 1960). Bottom heat for the containers has been recommended to speed germination and is also recommended during periods when cold nights can occur (Loomis 1950; Muirhead 1961). It should be noted that there is an allelopathic potential of the dry fruit of this species. Substances that inhibit germination were found in the pericarp (Khan 1982).

Germination is hypogeal (Tomlinson 1960). When a seed germinates, the shoot grows but the seed remains underground. With the appearance of an elongated second leaf, seedlings should be transplanted to individual containers containing soil mix enriched with leaf mold (Muirhead 1961). The transplants should be grown in partial shade to prevent excessive drying of the seedlings. During the subsequent growing period, the seedlings should be acclimated to heat by gradually removing the shade.

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Agavaceae—Century-plant family

Yucca L.

yucca

Robert R. Alexander, Floyd W. Pond, and Jane E. Rodgers

Mr. Alexander and Mr. Pond retired from the USDA Forest Service's Rocky Mountain Forest and Range Experimental Station; Ms. Rodgers is at the Point Reyes National Seashore, Point Reyes, California

Growth habit and occurrence. There are about 30 species of yucca native to North America and the West Indies. Although most of these long-lived, evergreen plants grow in the arid southwestern United States and on Mexican tablelands, yuccas are found up to 2,400 m in elevation in the mountains of Colorado (Arnott 1962; Webber 1953). Four western species are considered here (table 1). Great Plains yucca is a small acaulescent shrub 1 to 2 m tall, with narrow, swordshaped, spine-tipped, upright leaves 6 to 12 mm wide. Soaptree yucca is a medium to large caulescent shrub up to 9 m tall, with similar but wider (5 cm) and longer leaves (Arnott 1962; McKelvey 1947; Webber 1953). Tree-like in form, Joshua tree can exceed trunk lengths of over 3 m, with pseudodichotomous branching and long dark green leaves (Cornett 1991). Extensive stands of this sturdy tree can be found scattered throughout the Mojave Desert. The most common yucca in desert areas is Mohave yucca, a shrub or tree-like yucca reaching 1 to 5 m in height with rosettes at its tips (Jaeger 1940) .

Natural reproduction by seed is limited because of low rainfall (McKelvey 1947; Webber 1953). Most new plants sprout from underground rhizomes. Early growth of seedlings is very slow, and they often retain their succulent juvenile leaves for a year (Webber 1953). Soaptree yucca seedlings observed over a period of time on the Jornada Experimental Range in New Mexico averaged only about 20 cm high when 16 years old (Campbell and Keller 1932). At Joshua Tree National Park, it has been observed that Joshua tree and Mohave yucca grow 10 to 15 cm in their first year and roughly 2.5 cm annually thereafter (CALR 1995).

Uses. Yuccas are an important resource for Native Americans in the Southwest and Mexico. The buds, flowers, and legumes can be eaten raw, roasted, or boiled. The flower stalks of soaptree yucca can also be roasted like mescal. Rope, mats, sandals, baskets, and burlap cloth have been made from the fibers of the leaves. The roots of soaptree yucca, known as *amole*, have saponifying properties and have been used as a soap and as a laxative (Kearney 1969; Webber 1953). Bean and Saubel (1972) report that as a soap plant, Mohave yucca (the roots are called *hunuvat* by the Cahuilla) is one of the most famous in the Southwest. The inflorescent shoots of capsular yuccas are highly palatable to livestock and wildlife, and soaptree yucca has been used as an emergency ration for livestock during periods of drought. The chopped stems, when mixed with feed concentrates such as cottonseed meal, are palatable and nourishing (Kearney 1969; Webber 1953). Around the turn of the century, Joshua tree saw brief but unsuccessful commercial use as paper pulp and surgical splints (McKelvey 1938). These species have been cultivated occasionally as ornamentals; other species not covered here are commonly used horticulturally.

Table 1—*Yucca,* yucca: nomenclature and occurrence

Scientific name & synonym(s)	Common name(s)	Occurrence
***Y. brevifolia* Engelm.**	**Joshua tree,** tree yucca	Mojave Desert to SW Utah & W Arizona
***Y. elata* (Engelm.) Engelm.** *Y. radiosa* (Engelm.) Trel.	**soaptree yucca,** palmilla, soapweed, Spanish-bayonet	SW Texas, NW to central New Mexico & W central Arizona; Iron & Washington Cos., Utah
***Y. glauca* Nutt.** *Y. angustifolia* Pursh	**Great Plains yucca,** beargrass, soapweed, Spanish-bayonet	Texas N through Rocky Mtns & Great Plains to Montana & North Dakota
***Y. schidigera* Roezl ex Ortgies**	**Mojave yucca,** Spanish-dagger	S Mojave Desert, NW Sonoran Desert to Nevada, Arizona, & N Baja California

Source: Little (1979).

Flowering and fruiting. The greenish to creamy white flowers are perfect. They appear on terminal panicles from mid-May to mid-July (table 2). Under favorable environmental conditions, plants begin bearing flowers when about 5 to 6 years old. Soaptree yucca bears about 75 to 200 flowers per stalk, but only about 30% of these produce fruits (Campbell and Keller 1932). The fruit is a dehiscent capsule containing 120 to 150 flat, ovoid, black seeds (Campbell and Keller 1932; Ellis 1913). Capsules ripen from mid-July to late September (table 2). Seeds (figures 1 and 2) are wind disseminated in September and October.

Yucca pollination seldom occurs without the aid of females of 2 moth species—the yucca moth, *Pronuba yuccasella* (Riley), and *Prodoxus quinquepunctellus* (Chambers). These moths gather the pollen, place it in the stigmatic tube, and lay their eggs. The larvae feed exclusively on the maturing seeds but usually consume only a small (20%) portion (Bailey 1962; Ellis 1913; McKelvey 1947; Webber 1953).

Collection of fruits. Because the capsules are dehiscent, fruits should be collected just before or at the time the capsules open. They may be picked by hand or stripped from the plants onto canvas (Alexander and Pond 1974).

Extraction and storage of seeds. Seeds are easily extracted from dry capsules by hand if the sample is small (Alexander and Pond 1974). With larger samples, dry capsules should be run through a tumbler, revolving box, or drum with screen sides that permit the seeds to fall out. Chaff and other debris can then be winnowed or screened out. Cleaned seeds average 50,000/kg (22,680/lb) for soaptree and Great Plains yuccas (Arnott 1962) and 9,250/kg (4,200/lb) for Joshua tree and Mohave yucca. Seeds have been satisfactorily stored dry at room temperatures, so although no storage tests have been done, the seeds are obviously orthodox in storage behavior.

Pregermination treatments. Pretreatment is apparently not needed for successful germination (Arnott 1962), but there is evidence that yuccas exhibit some degree of hardseededness (Webber 1953). The germination period can be reduced by soaking seeds in water for 24 hours at room temperatures or by mechanically scarifying or removing the hard seedcoat at the hilum end.

Germination tests. Germination tests for soaptree and Great Plains yuccas have been run at temperatures between 28 and 32 °C, with soaked seeds placed between the folds of moist cotton. The germinative energy of both species after 4 days varied from 45 to 98% (72 samples), with the majority of the samples tested ranging from 80 to 90% (Webber 1953). Tests have also been run in flats in a greenhouse with untreated seeds. Germination after 20 days was 96% for soaptree yucca and 80% for Great Plains yucca (Arnott 1962). After 5 months, however, only 20% of the Great Plains yucca seeds sown had produced living seedlings, whereas all the soaptree yucca germinants were still alive.

Germination tests of Joshua tree seeds found maximum germination at 20 to 25 °C and inhibition at 10 to 15 °C

Figure 1—*Yucca*, yucca: seeds of *Y. elata*, soaptree (**top**); *Y. brevifolia*, Joshua tree (**center**); *Y. schidigera*, Mojave yucca (**bottom**).

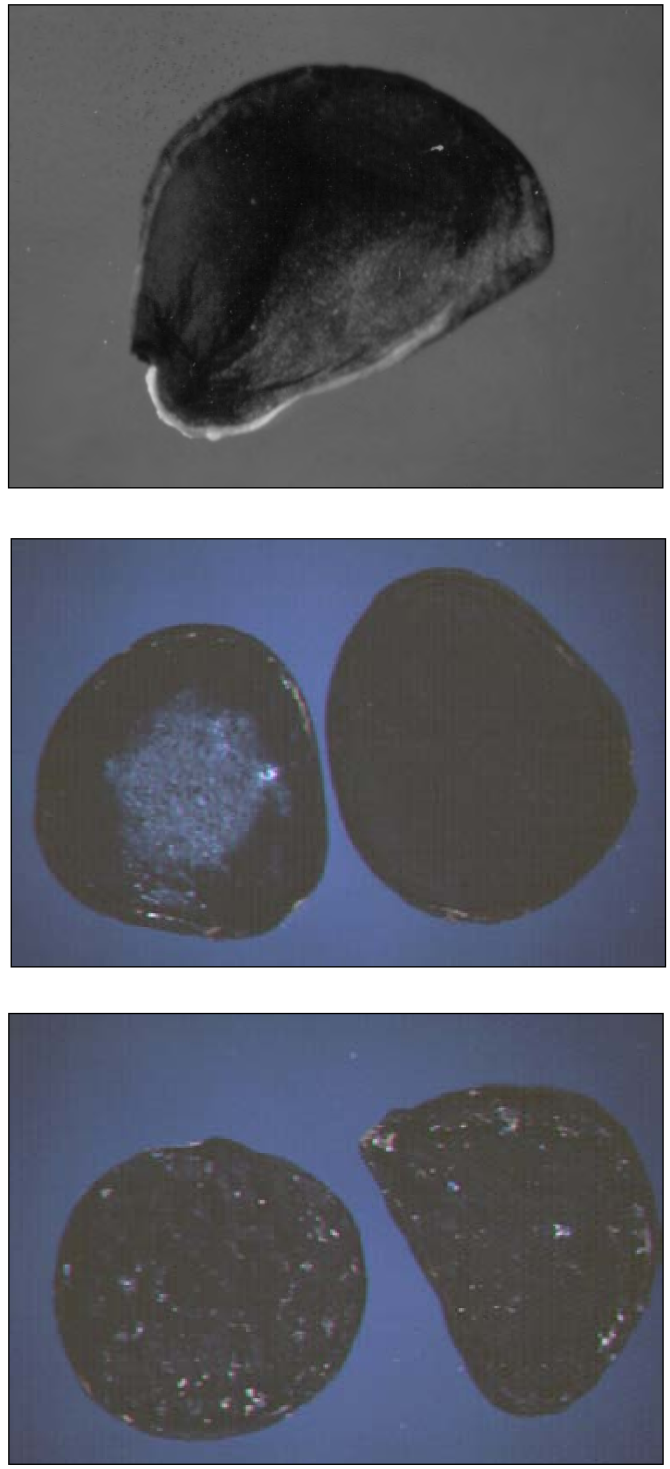
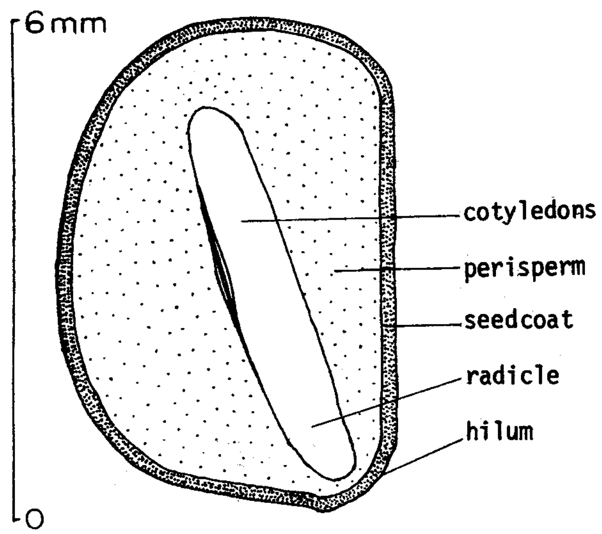


Table 2—*Yucca,* yucca: phenology of flowering and fruiting

Species	Location	Flowering	Fruit ripening	Seed dispersal
Y. brevifolia	—	Mar 1–Apr 1	July 1–Aug 1	—
Y. elata	S Arizona, New Mexico, & Texas	May 15–July 15	Aug 1–late Sept	Sept–Oct
Y. glauca	E Colorado	May 15–June 30	July–Aug	Sept
Y. schidigera	—	Late Mar–early May	Aug–Sept	—

Sources: Kay and others (1977), Kearney and Peebles (1969), McKelvey (1937), Webber (1953).

Figure 2—*Yucca elata*, soaptree yucca: longitudinal section through the embryo of a seed.



(McCleary and Wagner 1973). Seeds do not require scarification for germination (CALR 1995; Went 1948). Kay and others (1977) found that germination remained around 90% for sealed seeds in 3 environments (room temperature, 4 °C, and –15 °C) even after 35 months in storage. Germination treatments are similar for Mohave yucca (CALR 1995).

Nursery practice and seedling care. Most plants in botanical gardens or landscape plantings have been either 2- to 3-year-old wildings transplanted from the field or vegetative propagules. Joshua Tree National Park has successfully transplanted older Mohave yucca and Joshua tree specimens (CALR 1995). A few individuals and private nurseries have raised yucca plants from seeds. Good germination was obtained by soaking seeds in water at room temperature for at least 24 hours before sowing in the spring. Germination usually begins in 1 to 2 weeks but may continue for 2 to 3 years. Seedlings should be mulched the first winter if there is danger of frost. Seedlings should be ready for outplanting the second year (Hester 1933; Webber 1953). Yucca seedlings are foraged upon by mule deer (*Odocoileus hemionus*), rabbits (*Sylvilagus* spp.), woodrats (*Neotoma* spp.), and ground squirrels (*Citellus* spp.) (Cornett 1991).

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Z

Zamiaceae—Sago-palm family

Zamia pumila L.

coontie

W. Gary Johnson

Mr. Johnson retired from the USDA Forest Service's National Seed Laboratory

Synonyms. *Zamia angustifolia* Jacq., *Z. debilis* Ait., *Z. floridana* A. DC., *Z. integrifolia* Ait., *Z. latifoliolata* Preneloup, *Z. media* Jacq., *Z. portoricensis* Urban, *Z. silvicola* Small, and *Z. umbrosa* Small.

Other common names. Florida arrowroot, sago [palm] cycad, comptie, Seminole-bread.

Growth habit, occurrence, and use. Coontie is a cycad (a low, palm-like plant) with the trunk underground or extending a short distance above ground. It is native to Georgia, Florida, and the West Indies and is found in pine–oak woodlands and scrub, and on hammocks and shell mounds. About 30 *Zamia* species are native to the American tropics and subtropics. *Zamia* classification in Florida has long been the subject of controversy. Traditionally, several species have been recognized, but many botanists now believe that all *Zamia* taxa in Florida belong to a single species (FNAEC 1993).

The taproot gradually contracts, pulling the plant downward, leaving only the upper part of the stem above soil level. Coontie fixes nitrogen in upward-growing branching roots that terminate in nodules with cyanobacteria (Dehgan 1995). Coontie lacks lateral buds and thus has no true lateral branches. However, branching sometimes does occur, by division of the terminal bud (Dehgan 1995). The leaves are pinnately compound with dichotomously branched parallel veins. The seeds remain attached to the seedlings for 2 or more years after germination. The cotyledons never emerge from the seed (Dehgan 1995).

Coontie was once common to locally abundant but is now considered endangered in Florida. The starchy stems of coontie, after water-leaching to remove a poisonous glycoside, were eaten by the native people and early settlers (FNAEC 1993; Witte 1977). It is considered a good candidate for local landscaping (Witte 1977).

Flowering and fruiting. Coontie is a cycad, a cone-bearing gymnosperm, with male and female cones appearing on different plants. The male cones are cylindrical, 5 to 16 cm long, and often clustered 2 to 5 per plant. The female cones are elongate-ovoid, up to 5 to 19 cm long (LHBH 1976; FNAEC 1993). The period of receptivity and maturation of seed is December to March (FNAEC 1993). Insects (usually beetles or weevils) pollinate coontie. Good seed set is helped by hand-pollination (Dehgan 1995).

Collection of cones, extraction, and storage. Two seeds are produced per cone scale. The seeds are drupe-like, bright orange, 1.5 to 2 cm long (FNAEC 1993). The seeds may be collected from dehiscing cones in the winter (January in Gainesville, Florida). The pulpy flesh should be partially dried by spreading out the seeds to air-dry for about a month. Then, the pulp should be removed and the seeds should be washed, scrubbed, and air-dried (Witte 1977). Another method involves soaking the seeds 24 hours in water, then putting the seeds with moist sand in a wide-mouth jar and using a variable-speed drill with an attached long-stemmed wire brush to remove the fleshy seed coat (sarcotesta) without damaging the stony layer (sclerotesta) (Dehgan and Johnson 1983). Seeds stored for 1 year at 5 °C germinated as well as or better than fresh seeds (Witte 1977).

Pregermination treatments and germination tests. The fleshy seedcoats contain a growth inhibitor; the stony layer is up to 2 mm thick and is impermeable to water; and the embryo is partially dormant (Dehgan and Johnson 1983). Germination often takes 6 to 12 months. Removal of the fleshy seedcoat and scarification of the stony layer by cutting or cracking resulted in germination of 80 to 100% in 1 week (Smith 1978). Soaking seeds in sulfuric acid for 1 hour followed by 48 hours in gibberellic acid yielded a 92% germination in 6 weeks with intermittent mist (Dehgan 1996). Seeds average 340/kg (154/lb).

Nursery practice and seedling care. Cycads need well-drained soil with a pH of 6.5. The best growth occurs with a combination of slow-release fertilizer and monthly application of 300 ppm 20:20:20 N-P-K liquid fertilizer.

Seedlings should be provided with micronutrients applied once or twice per year or fertilizers that contain micronutrients should be used (Dehgan 1996). For prevention of root rot, the soil should not be allowed to remain wet longer than 1 to 2 days. The only major insect problems are with magnolia scale (*Neolecanium cornuparvum* (Thro)) and mealybugs (*Pseudococcus* spp.) (Dehgan 1996). Root-pruning helps to develop branched roots. The roots should be clipped where they join the stem, the cut surface dipped in indole butyric acid (IBA), and the plants misted for 2 weeks (Dehgan 1996).

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Rutaceae—Rue family

Zanthoxylum L.

prickly-ash

Franklin T. Bonner

Dr. Bonner is a scientist emeritus at the USDA Forest Service's Southern Research Station, Mississippi State, Mississippi

Growth habit and use. Most of the prickly-ashes—*Zanthoxylum* spp.—are large shrubs or small trees. The 3 species considered here are listed in table 1. In some areas they provide food and cover for wildlife. Their deciduous foliage is very aromatic, and the bark and fruit were once used for medicinal purposes, both as home remedies and in the drug industry (Vines 1960). The wood of *espino rubial* is used for boxes, pallets, local construction, and some furniture (Francis 1991).

Flowering and fruiting. The greenish white dioecious flowers are borne in inconspicuous axillary cymes on common prickly-ash and in large terminal cymes 5 to 15 cm in length on Hercules-club and espino rubial (figure 1) (Sargent 1965; Francis 1991). Phenological data are summarized in table 2. Prickly-ash fruits are globose, single-seeded capsules 5 to 6 mm in diameter. During ripening, they turn from green to reddish brown. At maturity, the round, black, shiny seeds hang from the capsules (figures 1–3).

Collection, extraction, and storage. Seeds may be stripped from clusters of mature capsules by hand as the capsules open, or entire clusters of unopened capsules may be picked when they turn reddish brown. Unopened capsules will discharge their seeds with gentle flailing after several days of air-drying. Seeds can be separated from capsule fragments by screening or winnowing (table 3). There are no storage test data known for this genus, but the seeds are probably orthodox in storage behavior. They can be dried to 10% moisture content without loss of viability, and seeds of common prickly-ash showed practically no loss in germinability after 25 months of storage in sealed containers at 5 °C (Bonner 1974).

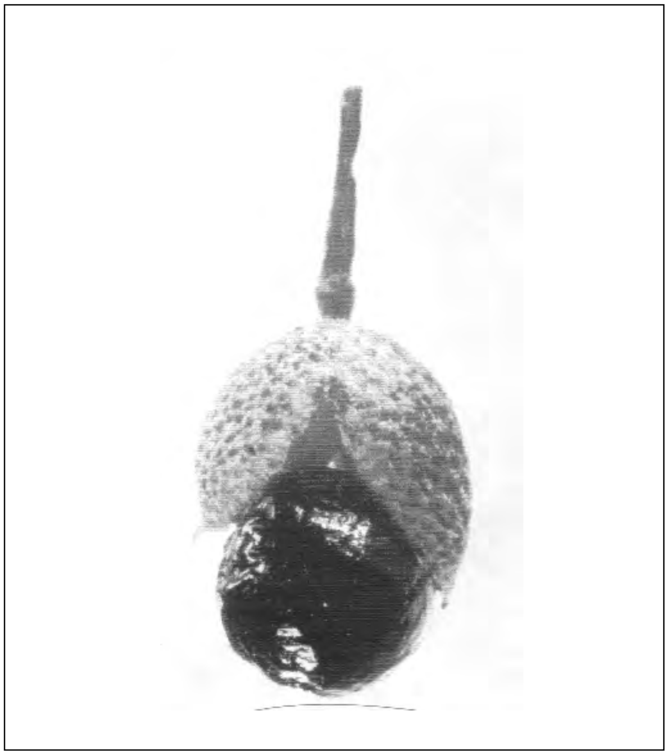
Figure 1—*Zanthoxylum clava-herculis*, Hercules-club: cluster of mature fruits.

Table 1—*Zanthoxylum,* prickly-ash: nomenclature, occurrence, and size

Scientific name	Common name(s)	Occurrence	Height at maturity (m)
Z. americanum **Mill.**	**common prickly-ash,** toothache-tree, northern prickly-ash	Quebec to North Dakota, S to Oklahoma & Georgia	8
Z. clava-herculis **L.**	**Hercules-club,** toothache-tree, southern prickly-ash, tingle-tongue, pepperbark	Oklahoma & Virginia, S to Florida & Texas	9–15
Z. martinicense **(Lam.) DC.**	***espino rubial,*** *pino macho*, *ayúa,* yellow hercules, *bosú*	Greater & Lesser Antilles, Trinidad & Tobago, E Venezuela	20–25

Sources: Bailey (1949), Francis (1991), Little (1979), Sargent (1965).

Figure 2—*Zanthoxylum clava-herculis*, Hercules-club: single carpel and seed.



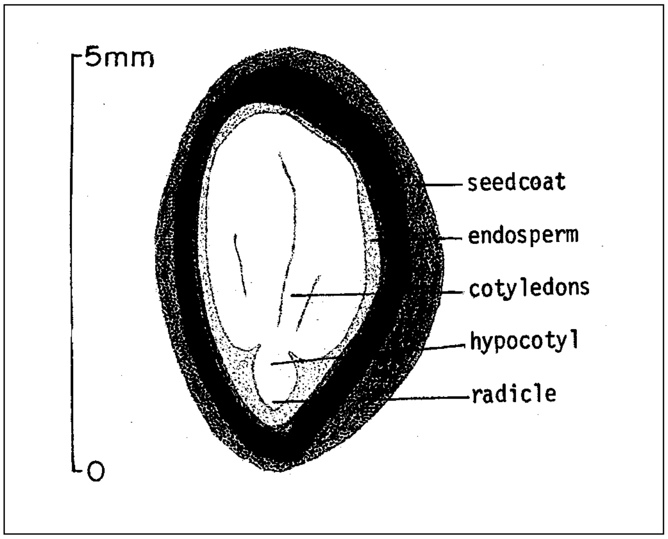
Germination. Seeds of common prickly-ash and Hercules-club exhibit strong dormancy, apparently imposed by the seedcoat. Scarification with concentrated sulfuric acid for 2 hours at about 21 °C has given fair results for Hercules-club, and stratification in moist sand for 120 days at 5 °C has helped germination of common prickly-ash (Bonner 1974). Germination of treated seeds of both species has been tested at diurnally alternating temperatures of 20 to 30 °C. (table 4). Seeds of espino rubial may have a similar dormancy, but there are no conclusive data. Untreated seeds sown in Puerto Rico produced only 5% germination (Francis 1991).

Table 2—*Zanthoxylum,* prickly-ash: phenology of flowering and fruiting

Species	*Flowering*	*Fruit ripening*
Z. americanum	Apr–May	June–Aug
Z. clava-herculis	Apr–June	July–Sept
Z. martinicense	Apr–May*	Aug–Sept

Sources: Vines (1960), Bonner (1974), Francis (1991).
* Primarily, but throughout the year in some areas.

Figure 3—*Zanthoxylum americanum*, common prickly-ash: longitudinal section of a seed (**left**) and seeds (**right**).



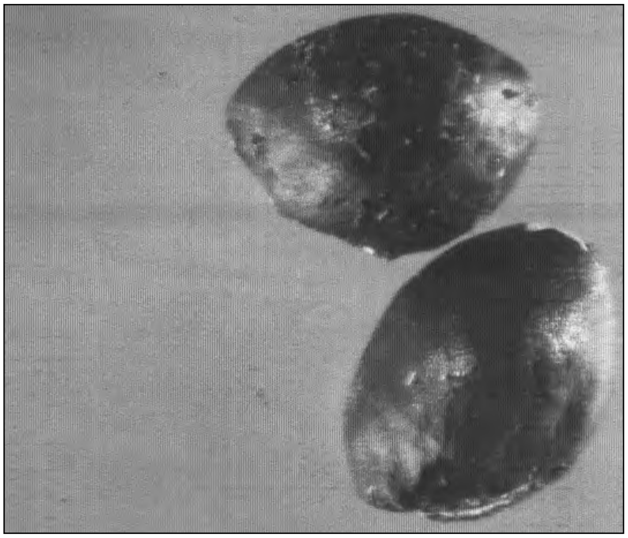


Table 3—*Zanthoxylum,* prickly-ash: seed data

		Seed	Cleaned seeds/weight				
	Place	moisture	Range		Average		
Species	**collected**	**(%)**	**/kg**	**/lb**	**/kg**	**/lb**	**Samples**
Z. americanum	Minnesota	—	48,100–72,590	21,800–32,900	56,490	25,600	3
Z. clava-herculis	Mississippi	10	33,100–37,050	15,000–16,800	35,000	15,900	2
Z. martinicense	Puerto Rico	—	—	—	75,000	34,020	—

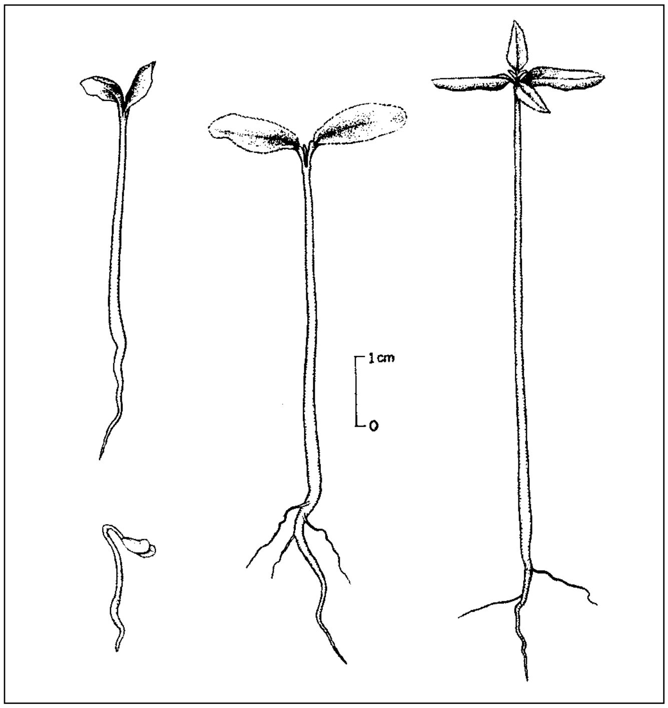
Sources: Bonner (1974), Francis (1991).

Table 4—*Zanthoxylum,* prickly-ash: germination test conditions and results

Species	Pregermination treatment	Daily light (hr)	Medium	Temp (°C) Day	Temp (°C) Night	Days	Germination rate Amt (%)	Germination rate Days	Germination % Avg (%)	Germination % Samples
Z. americanum	Stratified*	24	Sand	30	20	60	20	20	24	1
Z. clava-herculis	H_2SO_4	8	Blotterpaper	30	20	45	29	19	31	3

Source: Bonner (1974).
* In moist sand at 5 °C for 120 days.

Figure 4—*Zanthoxylum americanum*, common prickly-ash: seedling development at 1 (**left bottom**), 3 (**left top**), 13, and 18 days after



Nursery practice. Until more effective pregermination treatments are developed, fall sowing of untreated seed immediately after collection is recommended. Germination is epigeous (figure 4). Vegetative propagation from root cuttings and suckers is also possible (Dirr and Heuser 1987).

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Rhamnaceae—Buckthorn family

Ziziphus P. Mill.

jujube

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Growth habit and occurrence. There are about 100 species of this genus, which is composed of trees, shrubs, and lianas found chiefly in the tropical and subtropical regions of the world (Johnston 1963). There are 7 species native to the United States and Mexico, but none of them are of economic importance (Lyrene 1979). However, 2 exotic species, which are small deciduous trees, have been planted in this country for fruit production, wildlife food, and watershed protection (table 1). Common jujube—*Ziziphus jujuba* Mill.—the most commonly planted species, may grow to heights of 15 m at maturity (Vines 1960). This species has been cultivated for about 4,000 years in China and grown in this country for over 150 years (Bonner and Rudolf 1974; Lyrene 1979; Mowry and others 1953). Both common jujube and Christ-thorn—*Z. spina-christi* Willd.—are highly valued for fruit production and numerous agroforestry uses in Africa and Asia (Von Carlowitz 1986), where there are many selected cultivars.

Flowering and fruiting. The perfect, yellow flowers of common jujube appear in March to May in the United States, and the reddish-brown fruits mature from July to November. The fruits are globose to slender, fleshy drupes, which turn from green to dark reddish brown at maturity. If left on the tree, the fruits will turn black (Bailey 1939; Vines 1960). Common jujube drupes are oblong and 2.5 to 5 cm in length. They contain a 2-celled and 2-seeded pointed stone that is deeply furrowed, reddish brown to deep gray, oblong, and 2 to 2.5 cm long (figure 1) (Bonner and Rudolf 1974; Mowry and others 1953). Trees bear fruit as early as 1 to 4 years after planting (Lyrene 1979). Good crops are borne annually, and although they are popular for human consumption in Asia and Europe, the fruits from trees grown in the United States have apparently not been as edible. The crisp flesh of common jujube is whitish in color and has a sweet to subacid taste (Mowry and others 1953; Goor 1955; Vines 1960).

Collection, extraction, and storage. Jujube drupes may be picked by hand or flailed onto canvas sheets in the fall. Stones can be depulped by running them through a macerator with water and floating off the pulp. The cleaned stones are used as seeds. Seed yields are as follows (Goor 1955; Bonner and Rudolf 1974):

	Common jujube	Christ-thorn
Cleaned seeds/weight of drupes—kg/45 kg (lb/100 lb)	12–16 (25–35)	—
Cleaned seeds/weight—kg (lb)	1,650 (750)	1,500 (680)

No conclusive storage data are available for this genus, but dry storage at room temperature has been successful for Christ-thorn (Goor 1955). Because these seeds appear to be orthodox, storage at low moisture contents at 5 °C is suggested.

Pregermination treatments. Jujube seeds are moderately dormant and require treatment for prompt germination. Stratification recommendations for common jujube are 60 to 90 days in moist sand at 5 °C (Bonner and Rudolf 1974) or 3 months warm incubation, followed by 3 months cold stratification (Dirr and Heuser 1987). Some growers recommend scarification in sulfuric acid for 2 to 6 hours, followed by stratification at 5 °C for 60 to 90 days (Lyrene 1979). Very

Table 1—*Ziziphus*, jujube: nomenclature and occurrence

Scientific name	Common name(s)	Occurrence
Z. jujuba **Mill.**	**common jujube,** jujube, Chinese date	Native to Asia, Africa, & SE Europe; planted in S US from Florida to California; naturalized along Gulf Coast from Alabama to Louisana
Z. spina-christi **Willd.**	**Christ-thorn**	Native to arid & semi-aridregions of Africa & W Asia; planted in SW US

Sources: Bonner and Rudolf (1974), Vines (1960).

prompt germination was obtained for seeds of Christ-thorn in Israel by soaking them for 2 days in water at 21 to 38 °C. Shorter or longer periods were not as successful (Gindel 1947).

Germination tests. Germination tests with seeds treated as described above are summarized in table 2.

Nursery practice. Untreated stones of common jujube can be sown in drills in the fall; stones stratified for 90 days may be sown in the spring. They should be covered with 2.5 cm (1 in) of soil (Bonner and Rudolf 1974). In Israel, 2 days of water-soaking prior to sowing has been recommended for Christ-thorn (Gindel 1947). Intact drupes may also be sown in the nursery (Goor 1955). Germination is epigeal. Vegetative propagation is possible by root cuttings (Dirr and Heuser 1987).

Figure 1—*Ziziphus jujuba*, common jujube: longitudinal section through 2 seeds in a stone (**left**), exterior view of a seed after removal from a stone (**center**), exterior view of a seed (**right**).

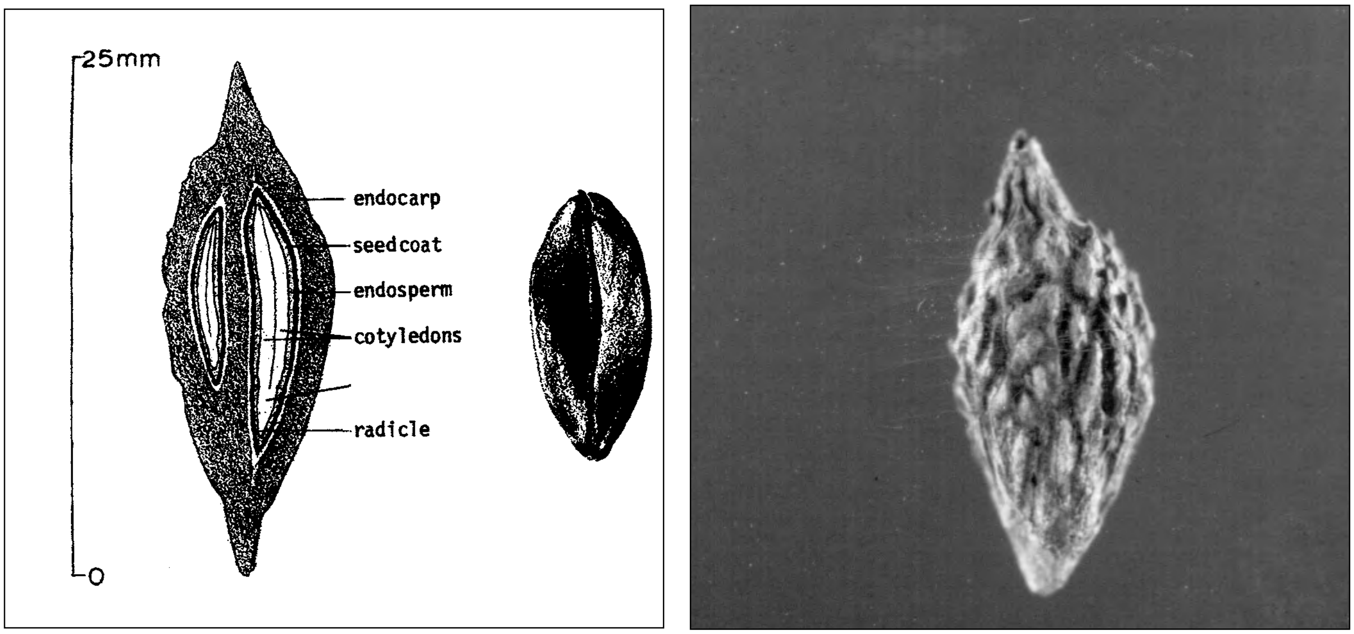

Table 2—*Ziziphus,* jujube: germination test conditions and results								
	Germination test conditions				Germination rate		Germination %	
		Temp (°C)			Amt		Avg	
Species	Medium	Day	Night	Days	(%)	Days	(%)	Samples
Z. jujuba	Sand	30	21	50	—	—	31	2
Z. spina-christi	—	38	38	4	65	2	85	4

Source: Bonner and Rudolf (1974).

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Chenopodiaceae—Goosefoot family

Zuckia brandegei (Gray) Welsh & Stutz ex Welsh

siltbush

Nancy L. Shaw, Rosemary L. Pendleton, and Emerenciana G. Hurd

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Other scientific names. *Zuckia arizonica* Standley, *Atriplex brandegei* (Gray) Collotzi, *Grayia brandegei* (Gray).

Other common names. spineless hopsage, apple-bush, saltbush.

Growth habit, occurrence, and use. Siltbush is an autumn-deciduous shrub or sub-shrub ranging from 0.1 to 0.8 m in height (Goodrich and Neese 1986). Stems of the current year are thornless and erect or ascending, branching from a persistent, woody base. Leaves are gray-scurfy and entire to lobed. Overwintering leaf buds are prominent, axillary, and globose (Welsh and others 1987).

A narrowly distributed edaphic endemic, siltbush is largely restricted to the Colorado River drainage of central and eastern Utah and northeast Arizona, southwest Wyoming, western Colorado, and northwest New Mexico (Smith 1974; Stutz and others 1987; Welsh and others 1987). It grows in isolated monotypic populations on weathered, often saline or seleniferous, fine-textured to sandy substrates in desert shrub to lower juniper communities at elevations from 1,280 to 2,240 m (Goodrich and Neese 1986). Although a poor competitor, siltbush is a stress-tolerant species capable of surviving on sites unfavorable for establishment of other species and enduring long periods of adverse environmental conditions. It is a potential revegetation species for mined lands and other disturbed sites within its native range (Pendleton and others 1996).

Geographic races and hybrids. Type specimens of *Zuckia brandegei* were originally described as *Grayia brandegei* Gray (Gray 1876). Stutz and others (1987) later identified 2 chromosome races. Diploid populations (2X = 18) are small plants with narrow, linear leaves that are mostly restricted to south-central Utah and northeastern Arizona. Tetraploids (4X = 36) are larger plants with large ovate to lanceolate leaves that occur primarily as isolated populations in northeastern Utah, south-central Wyoming, eastern Colorado, and northwestern New Mexico. Based on distribution patterns and interpopulation differences, Stutz and others (1987) suggested that the larger plants may be autotetraploids of polyphyletic origin and designated them *G. brandegei* A. Gray var. *plummeri* Stutz and Sanderson var. nov. in honor of A. P. Plummer, pioneer shrub scientist.

Welsh (1984) and Welsh and others (1987) transferred *G. brandegei* to the genus *Zuckia*, renaming it *Z. b.* (Gray) Welsh & Stutz ex Welsh var. *brandegei* and reduced *Z. arizonica* Standley, the only species previously in the genus, to *Z. b.* Welsh & Stutz ex Welsh var. *arizonica* (Standley) Welsh. *Z. b.* var. *arizonica* is diploid (Sanderson 2000) and is found in scattered populations from northern Arizona to northeastern Utah (Goodrich and Neese 1986). Dorn (1988) later transferred *G. b.* var. *plummeri* to *Z. b.* var. *plummeri* (Stutz & Sanderson) Dorn. Transfers from *Grayia* to *Zuckia* were made on the basis of fruit morphology, branching pattern, and pubescence type. Goodrich and Neese (1986) concurred with these distinctions but with the reservation that *Grayia* "could logically be expanded to include *Zuckia*."

Naturally occurring hybrids of siltbush with shadscale (*Atriplex confertifolia* (Torr. And Frem.) Wats.) and Castle Valley clover (*A. gardneri* (Moq.) D. Dietr. var. *cuneata* (A. Nels.) Welsh) were reported by Drobnick and Plummer (1966). Blauer and others (1976) obtained viable seeds, but no seedlings, by artificially pollinating pistillate flowers of fourwing saltbush with tetraploid siltbush pollen.

Flowering and fruiting. All siltbush varieties are monoecious and heterodichogamous (Pendleton and others 1988). Plants are protogynous (producing pistillate, then staminate flowers) or protandrous (producing staminate, then pistillate flowers) in about equal numbers. Within each plant, temporal separation of pistillate and staminate phases is nearly complete, generally precluding self-fertilization.

Staminate flowers each consist of 4 or 5 stamens and a 4- or 5-lobed perianth. They develop in clusters of 2 to 5 in bract axils (Goodrich and Neese 1986; Welsh and others 1987). Pistillate flowers are 1 to several in bract axils with each enveloped by 2 united bracts. The bracts are either dorsiventrally flattened and unequally 6-keeled with the seed horizontal (*Z. b*. var. *arizonica*) (figures 1 and 2) or obcompressed and thin-margined with the seed vertical (*Z. b.* var. *bradegei* and *Z. b.* var. *plummeri*) (Goodrich and Neese 1986; Welsh and others 1987) (figures 1 and 2). Plants of all varieties flower in late spring or summer and fruits ripen in mid to late summer or fall (Blauer and others 1976; Pendleton and others 1988) (table 1).

Protogynous plants generally produce more seeds, but protandrous plants may be equally productive in wet years or in years with low seed predation (Pendleton and others 2000). Fruits are dispersed slowly, with some usually remaining dormant on the plant through winter (Blauer and others 1976). Seeds are light yellowish brown at maturity (Hurd and Pendleton 1999) (figure 3). The outer layer of the seedcoat is elastic when imbibed. The embryo is well developed, with pale yellow cotyledons and an elongate, inferior radicle encircling the perisperm (figure 3). Seedling development is epigeal (figure 4).

Collection of fruits and seed extraction and cleaning. Fruits are collected by hand- stripping or beating and air-dried. Coarse debris may be removed with an air-screen machine or a seed blower, or by screening. Careful rubbing to remove bracts prevents radicle damage. The final product may consist of debracted utricles (Meyer and Pendleton 1990; Pendleton and Meyer 1990) or seeds (figure 3). Weight of bracted utricles and seeds and seed fill data are provided in table 2.

Figure 2—*Zuckia brandegei*, siltbush: utricle (**left**) and seed (**right**)

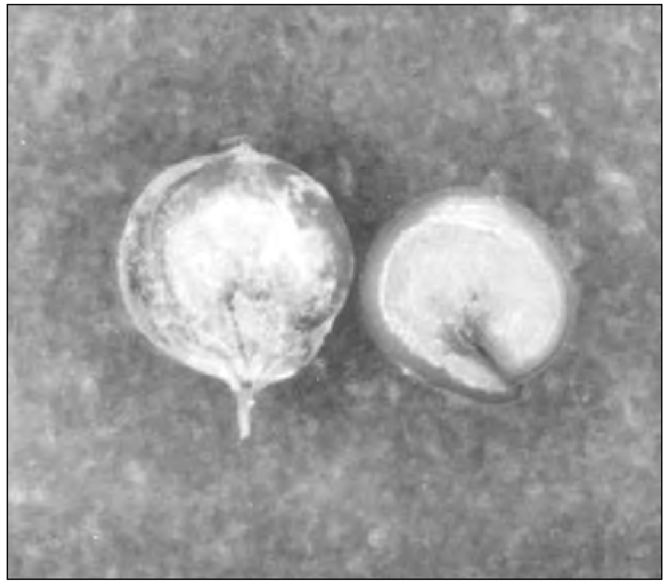
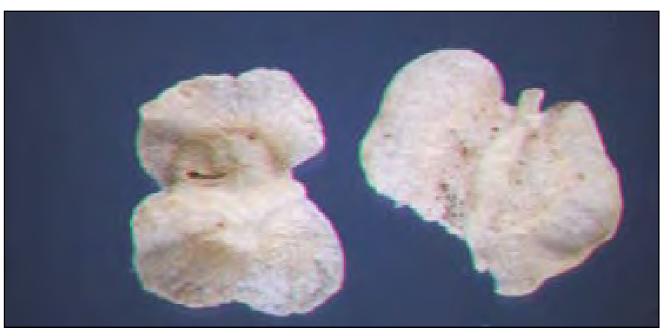


Figure 1—*Zuckia brandegei*, siltbush: bracted utricles.



Storage. Germination of seeds incubated at 1 to 3 °C in constant darkness was 87% after 2 years of storage in cloth bags in a warehouse (Stevens and Jorgensen 1994; Stevens and others 1981). Germination from year 2 to year 4 was 88%, dropping to 57% by year 5, 13% by year 7, and 0% after 15 years. Viability of bracted utricles stored in paper bags at room temperature and debracted utricles from the same collection stored in a freezer at – 80 °C was 97% after 7 years as determined by tetrazolium chloride testing (Hurd and Pendleton 1994).

Pregermination treatments. Germination experiments have been conducted with seeds of *Z. b.* var. *brandegei* and *Z. b.* var. *plummeri*. Seeds of warm-winter populations may germinate opportunistically over a wide range of

Table 1—*Zuckia brandegei*, siltbush: phenology of flowering and fruiting

Species	Location	Flowering	Fruit ripening	Seed dispersal
Z. brandegei	Central Utah	Mid-June–mid-Aug	Late Sept–early Oct	Jan or later
	Uinta Basin, Utah	May–June	Sept	—
	Sanpete Co., Utah	Mid-May–July	July–late Sept	—
	—	—	Sept 10–Dec 15	—

Sources: Blauer and others (1976), Goodrich and Neese (1986), Pendleton and others (1988), Plummer and others (1968).

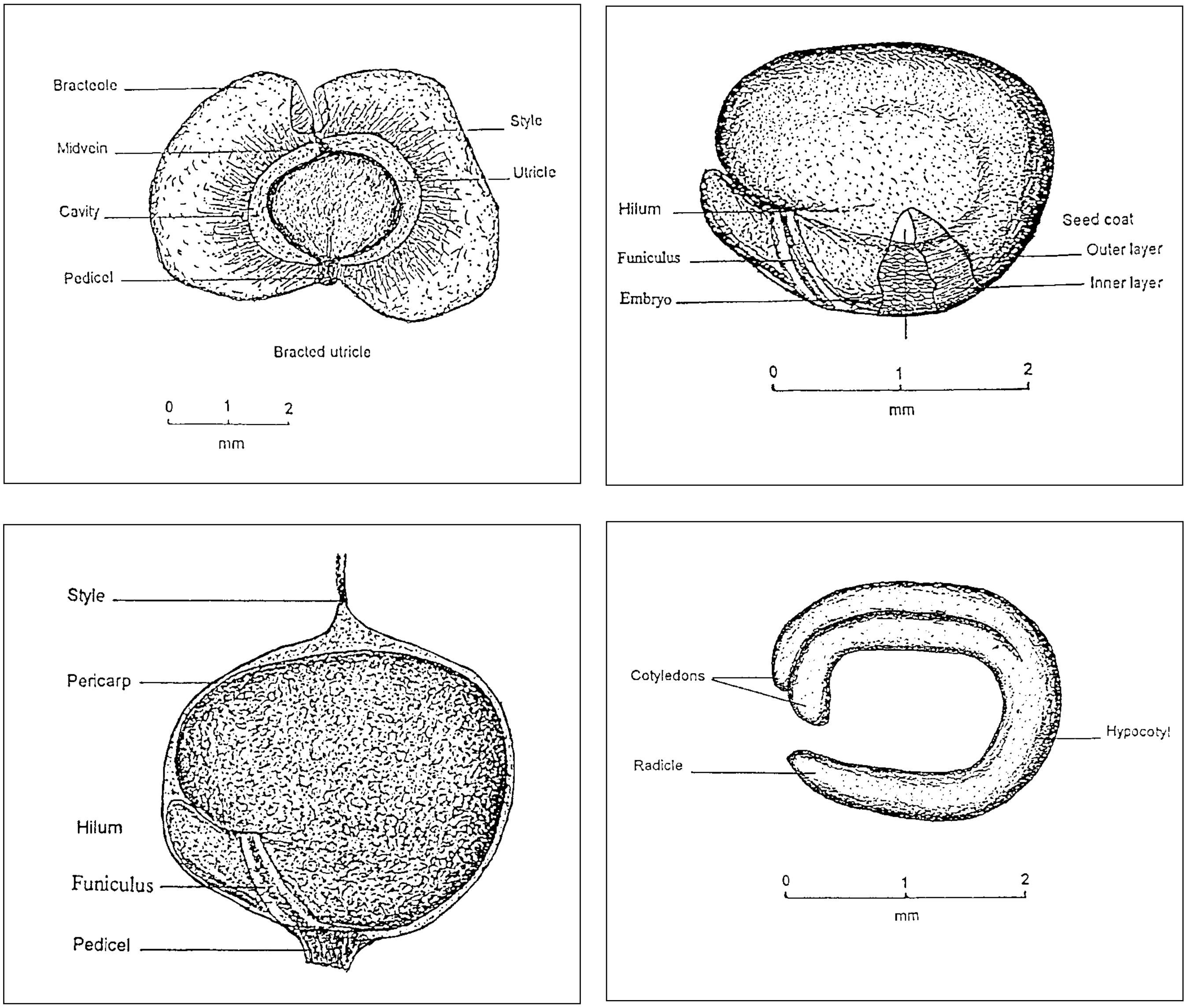


Figure 3—*Zuckia brandegei*, siltbush: bracted utricle (**top left**), seed (**top right**), utricle (**bottom left**), and embryo (**bottom right**).

constant temperatures (15 to 30 °C) when water is available (Meyer and Pendleton 1990). Seeds of cold-winter populations are dormant at fall and winter temperatures, germinating in early spring following exposure to overwinter chilling. Germination generally increased with duration of wet prechilling at 1 °C for up to 8 weeks, dry after-ripening for up to 14 months, or removal of bracts (Meyer and Pendleton 1990; Pendleton and Meyer 1990).

Techniques and criteria recommended for characterizing normal seedlings, excising embryos, and testing viability are as described for spiny hopsage (Shaw 1992):

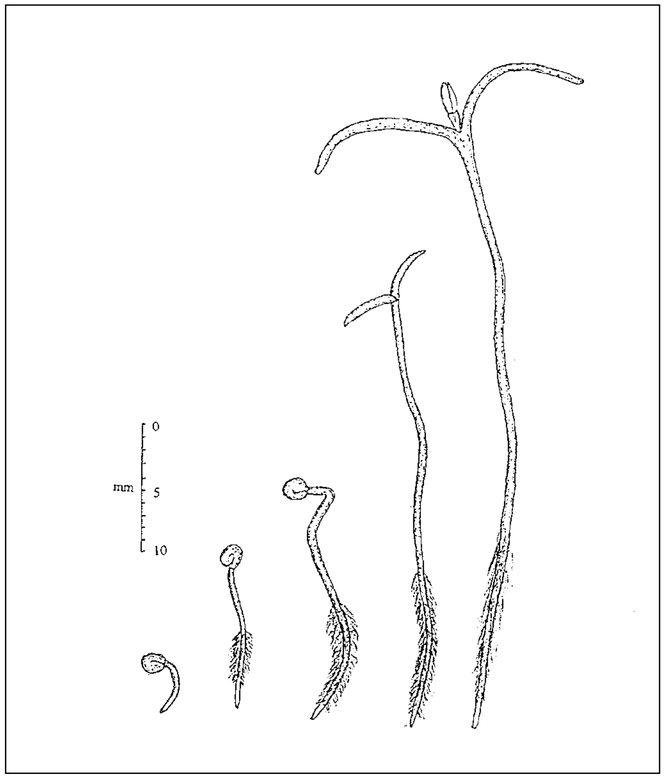
- Normal seedling—Epigeal, with thin, 10- to 15-mm-long hypocotyls; small, narrow cotyledons; short epicotyl; and well-developed root hairs (figure 4).
- Excised embryo—Seeds soaked in water at 28 °C for 12 hours and then drained can have their embryos excised with sharp needles; these embryos germinate rapidly at 15/5 or 15 °C and should be evaluated for presence of normal seedlings.
- Viability—Seeds soaked in water at 28 °C for 12 hours, and then drained can be pierced through the perisperm with a sharp probe or needle, then they are

Table 2—*Zuckia brandegei*, siltbush: fruit and seed characteristics

Species	Bracted utricles (x1,000)/weight				Seeds (x1,000)/weight				Filled seed %	
	Range		Average		Range		Average			
	/kg	/lb	/kg	/lb	/kg	/lb	/kg	/lb	Range	Average
Z. brandegei	263–312	119–142	284	129	555–769	252–349	—	—	5–27	16
Z. brandegei var. *arizonica*	372–1,061	169–481	732	332	420–794	191–360	418–561	190 – 254	7–21	15

Sources: Pendleton and others (1988), Plummer and others (1968), Smith (1974).

Figure 4—*Zuckia brandegei*, siltbush: seedling development.



soaked in a 1% 2,3,5-triphenyl tetrazolium chloride solution for 4 to 8 hours at 28 °C; the seedcoat is translucent after soaking, making excision unnecessary for evaluation of staining.

Nursery culture and direct seeding. Because few data are available, recommendations for spiny hopsage (see Grayia, page 567) may be used as guidelines for establishing siltbush from seed. Based on studies conducted in south-central Utah, Monsen (1996) found that siltbush seedlings develop more rapidly than those of spiny hopsage. Root systems of bareroot stock are much more extensive after 1 growing season. Palatability is low to moderate (Monsen 1996; Stutz 1995). Plants may attract rodents, other small animals, and occasionally deer.

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