Table 4—*Quercus,* oak: germination test conditions and results

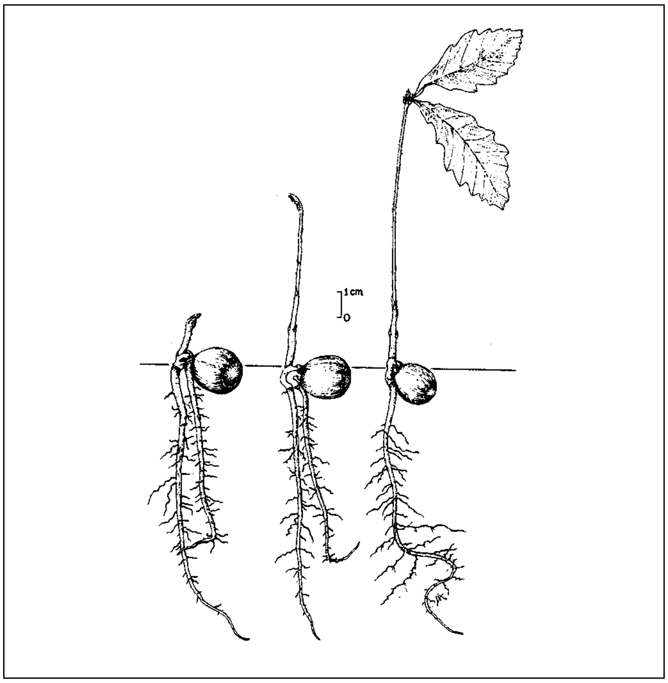
Species	Cold stratification (days)	Germination test conditions: Medium	Temp (°C) Day	Temp (°C) Night	Day	Germinative rate Avg (%)	Germinative rate Days	Germination (%)	Germination Samples
Q. acutissima	—	—	—	—	—	—	—	98	1
Q. agrifolia	0	—	—	—	15–40	—	—	73	1
Q. alba	0	Kimpac	30	20	30–98	39–93	10–41	50–99	21
Q. bicolor	0	Sand	21–35	10–16	60–240	65–95	80–120	78–98	3
Q. cerris	0	Germinator	22	20	30	—	—	33–76	3
Q. chrysolepis	0–60	Peat/loam	30	20	56–60	—	—	56–75	2
Q. coccinea	30–60	Kimpac	30	20	30–60	97	16	94–99	7
Q. douglasii	0	Sand	30	20	30	—	—	70–72	4
Q. durmosa	30–90	Sand	30	20	28	—	—	80–90	3
Q. ellipsoidalis	60–90	Sand	30	21	30–60	80–93	18–26	95	5
Q. falcata	30–90	Sand	23–27	23–27	30–57	62–74	22–36	75–100	8
Q. gambelii	14	—	—	—	—	92	15	92	1
Q. garryana	0	Loam	30	21	90	—	—	77–100	4
Q. ilicifolia	60–120	Sand/perlite	30	20	36–81	—	—	86–94	12
Q. imbricaria	30–60	Sand	24	16	30	—	—	28–66	2
Q. kelloggii	30–45	Sand	30	21	30–40	—	—	95	1
Q. laevis	60–90	Sand	27	23	7	—	—	82	2
Q. laurifolia	0	Soil			108	—	—	50	1
	14–90	Sand	27	23	30–90	—	—	45–92	6
Q. lyrata	0	Sand	21–35	10–16	160	82	100	84	1
	42	Sand	27	23	128	—	—	82	4
Q. macrocarpa	30–60	Sand	30	20	40	28-85	25-45	45	11
Q. marilandica	90	—	—	—	—	—	—	91	1
Q. michauxii	0	Soil	32	21	50–84	23–48	40–60	49	2
	30	Soil	32	21	50	86	22	98	1
Q. muehlenbergii	0	Kimpac	30	20	45	95	8	98	4
Q. nigra	30–60	Sand/peat, Kimpac	30–32	20–21	52–73	54–80	31–73	60–94	12
Q. pagoda	60–120	Sand/perlite	30	20	30–40	85–90	21–38	86–98	11
Q. petraea	0	Sand	30	20	30	—	—	65–74	7
Q. phellos	30–90	Soil, Kimpac	32	21	45–100	41	55	67	4
	0	Soil	32	21	90	83	47	89	1
Q. prinus	0	Sand	27	18	60	72–78	40	82	3
Q. robur	0	Sand	25	16	30–60	—	—	81	4
Q. rubra	30–45	Sand	30	20	40–60	39–85	13–42	58	11
	70	Sand/peat	20	20	20	80	10	100	1
Q. shumardii	60–120	Soil, Kimpac	32	21	29–50	53–66	21–28	72–82	3
Q. sinuata	0	Kimpac	30	20	30	81	21	87	4
Q. stellata	0	Sand, Kimpac	30	20	45–60	42–93	10–45	54–98	7
Q. suber	0	Sand	27	27	20–30	—	—	73-100	5
Q. texana	60–90	Soil	32	21	58–87	—	—	60–69	20
Q. turbinella		Sand	38	5	—	—	—	95	2
Q. vaccinifolia	0	Loam	23	19	180	38	30	43	1
Q. variabilis	0	Sand	25		28	55	28		2
Q. velutina	30–60	Sand	27	18	30–50	—	—	47	5
Q. virginiana	0	Kimpac	30	20	—	92	8	97	4
Q. wislizenii	30–60	Sand/peat	30	20	69	—	—	75	1

Sources: Dirr and Heuser (1987), Korstian (1927), Larsen (1963), Olson (1974), Swingle (1939).

fall-sowing in the southern part of the country is that mild winters may not completely satisfy the stratification requirement of dormant black oaks, and germination in the spring may be slow and erratic. Another disadvantage is prolonged exposure to predators, such as grackles (*Quiscaluis spp.*) and blue jays (*Cyanocitta cristata*), that dig up acorns from the beds. If spring-sowing is used (very common in the South), the acorns should be stratified.

Acorns should be drilled in rows 20 to 30 cm (8 to 12 in) apart and covered with 6 to 25 mm ($^1/_4$ to 1 in) of firmed soil. The planting depth should at least be equal to the average acorn diameter. Desirable seedbed densities are 100 to

Figure 3—*Quercus macrocarpa*, bur oak: seedling growth 1, 5, and 12 days after germination



160 seedlings/m^2 (10 to 15/ft^2) (Williams and Hanks 1976), or less. For cherrybark oak, a study of bed densities from 43 to 108/m^2 (4 to 10/ft^2) showed that the lowest density produced more plantable seedlings per weight of seed, even though nursery costs were approximately 20% higher (Barham 1980). Another study with this same species found that 86/m^2 (8/ft^2) produced the greatest number of plantable seedlings (Hodges 1996). Fall-sown beds should be mulched with sawdust, ground corncobs, burlap, straw, or similar materials. Where high winds may blow the mulch, some sort of anchoring device, such as bird netting, must be used. Mulches reduce erosion and frost heaving and provide some protection against rodents and birds. In the spring, after frost danger is past, the straw and hay mulches should be removed, but sawdust can remain on the beds. Partial shade has been found to improve germination of Nuttall (Johnson 1967) and cherrybark oaks (Hodges 1996) but is not commonly used for other oaks. The common planting stock for oaks is a 1+0 seedling.

Oaks can also be direct-seeded in the field but must be covered to control predation by animals. Spot-seeding at depths of 2 to 5 cm (1 to 2 in) have been successful for bur, chestnut, white and pin oaks in Kentucky (Cunningham and Wittwer 1984); white, northern red, and black oaks in Tennessee (Mignery 1975); and cherrybark, Nuttall, sawtooth, Shumard, and water oaks in Mississippi (Francis and Johnson 1985; Johnson 1984; Johnson and Krinard 1985). Rapid germination will also reduce losses to rodents and birds, so acorns direct-seeded in the spring should be stratified. In recent years, large areas have been seeded to oaks in the Mississippi River floodplain in Mississippi and Louisiana. Results have been mixed; some operations have been successful and others have not, but the reasons for failure have not always been understood. In these sites, control of competing vegetation is often necessary in the first few years.

Oaks in general are extremely difficult to propagate vegetatively on a commercial scale, although a few successes have been reported. Grafting and budding have been somewhat successful for ornamental selections (Dirr and Heuser 1987), and some advances have been made in tissue culture of certain oaks (Chalupa 1990; Gingas 1991).

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Rhamnaceae—Buckthorn family

Rhamnus L.

buckthorn

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Growth habit, occurrence, and use. Until recently, the buckthorn genus—*Rhamnus*—and the closely related genus *Frangula* have been treated as the single genus *Rhamnus* consisting of more than 125 species of evergreen or deciduous shrubs and trees with alternate branches and simple leaves with prominent pinnate veins (Hickman 1993). Kartesz and Gandhi (1994), however, used floral morphology and leaf venation, as well as anatomical features of xylem vessels to support segregation of *Frangula*. Under their treatment, *Rhamnus* spp. have winter buds protected with bud scales and arcuate leaf nerves. Both *Rhamnus* and *Frangula* are native to the temperate regions of North America, Europe, and Asia, and also occur in the Neotropics and southern Africa as shrubs and trees up to 1.5 m dbh and over 60 m tall (Johnston and Johnston 1978; Krüssmann 1985). The common name buckthorn, which is shared by both genera, may have arisen in Europe, where some of the species are thorny (Mozingo 1987; USDA 1937). *Rhamnus* is the Latinized form of the ancient Greek name for the genus. At least 14 species and subspecies are distributed within the United States (table 1) (USDA NRCS 2001).

European buckthorn, native to Europe and temperate Asia and widely naturalized in the northeastern United States, is a common old-field invader (Gill and Marks 1991) that grows to about 4 m in height with branches that may end in sharp thorns. The bark yields yellow and saffron-colored dyes. The black fruits have been collected for over a thousand years as the source of a strong cathartic and laxative that is so potent that its purgative properties may be retained in the flesh of animals that have consumed the fruit (Mozingo 1987).

Alder buckthorn has perhaps the broadest distribution of all the species native to North America. The specific epithet refers to its similarity to alder (*Alnus*) in leaf shape. The leaves are deciduous, and the wood has been used as a source of the finest charcoal for gunpowder (Everett 1982). It grows to a height of 1.5 m on moist mountain slopes and streambanks.

Spiny, hollyleaf, and island redberries are evergreen shrubs or small trees of California chaparral. The fruits of spiny and hollyleaf redberries may be preferred browse of deer (*Odocoileus* spp.) (Conrad 1987).

Alder buckthorn and European buckthorn are alternate hosts for crown rust—*Puccinia coronata* Corda.—which causes yellow leaf spot in the aecial stage. Economic damage by crown rust is confined to heavy damage in fields of oats grown in close proximity to hedges and fence-rows of buckthorns (Ziller 1974).

The dates of earliest known cultivation of species native to North America includes 1778 for alder buckthorn and the mid-1800's for spiny redberry (Krüssmann 1985).

Flowering and fruiting. The inconspicuous flowers are either perfect or imperfect and are borne in small axillary racemes, fascicles, or occasionally reduced to single flowers in alder buckthorn and spiny, hollyleaf, and island redberries. The shallow to deeply campanulate hypanthium is rimmed with 4 deltoid, thin and spreading sepals, with the upper part of the hypanthium falling after maturity and the lower part remaining around the developing fruit (Hitchcock and others 1961; Kartesz and Gandhi 1994). White to greenish white petals are equal to the sepals in number and alternating, or lacking. There are 4 stamens, and the anthers are shorter than filaments. The ovary has 2 to 4 cells. Flowers are unisexual in spiny, hollyleaf, and island redberries; alder buckthorn and European buckthorn plants may be dioecious. Flowers appear in the spring and fruits ripen several weeks to months later (Hubbard 1974).

Fruits are drupaceous, the berrylike pulpy mesocarp embedding several free 1-seeded stones (figure 1) (Johnston and Johnston 1978). Fruits are 6 to 8 mm in diameter; they are generally black in alder buckthorn and red in spiny, hollyleaf, and island redberries. Spiny, hollyleaf, and island redberries have 2 stones per fruit; alder buckthorn has 3 stones per fruit; and European buckthorn has 3 or 4 stones per fruit (figure 2). Stones are grooved on the outside (Kartesz and Gandhi 1994). Dispersal is mostly by birds.

Table 1—*Rhamnus,* buckthorn: nomenclature and occurrence

Scientific names & synonym(s)	Common name(s)	Occurrence
R. alnifolia **L'Hér.**	**alder buckthorn**	Transcontinental in S Canada, Maine to Virginia, Tennessee, W to Utah, California
R. arguta **Maxim**.	—	Introduced in Indiana
R. cathartica **L.**	**European buckthorn,** waythorn, common buckthorn	Europe & Asia; naturalized from Nova Scotia, Maine, S to Virginia, W to Montana, Wyoming, Utah, & California
R. crocea **Nutt.** *R. pilosa* (Trel.) Abrams	**spiny redberry,** redberry buckthorn	California to Baja California Sur, Arizona, & New Mexico
R. davurica **Pallas**	**Dahurian buckthorn**	Siberia to N China; introduced in Rhode Island, Pennsylvania, North Carolina, E to North Dakota, Nebraska
R. davurica **Pallas ssp. *nipponica* (Makino) Kartesz & Gandhi**	**Dahurian buckthorn**	Introduced in Rhode Island
R. ilicifolia **Kellogg** *R. crocea* Nutt. ssp. *ilicifolia* (Kellogg) C.B. Wolf *R. crocea* Nutt. var. *ilicifolia* (Kellogg) Greene	**hollyleaf redberry**	Oregon, California, Nevada, & Arizona
R. japonica **Maxim.**	**Japanese buckthorn**	Japan: introduced in Illinois
R. lanceolate **Pursh ssp. *glabrata* (Gleason) Kartesz & Gandhi** *R. lanceolata* Pursh var. *glabrata* Gleason	**lanceleaf buckthorn**	Virginia, Ohio, Tennessee, Alabama, W to South Dakota, Arkansas, Texas
R. lanceolate **Pursh ssp. *lanceolata***	**lanceleaf buckthorn**	Pennsylvania, Virginiana, W to Wisconsin, Indiana, Missouri, Tennessee, Alabama
R. pirifolia **Greene** *R. crocea* Nutt. var. *pirifolia* (Greene) Little *R. crocea* Nutt. ssp. *pirifolia* (Greene) C.B. Wolf	**island redberry**	S California to Mexico
R. serrata **Humb. & Bonpl. ex J.A. Schultes** *R. fasciculata* Greene *R. smithii* Greene ssp. *fasciculata* (Greene) C.B. Wolf	**sawleaf buckthorn**	Arizona, New Mexico, Texas
R. smithii **Greene** *R. smithii* Greene ssp. *typica* C.B. Wolf	**Smith buckthorn**	Colorado & New Mexico
R. utilis **Dcne.**	**Chinese buckthorn**	E China; introduced in Michigan & Illinois

Figure 1—*Rhamnus*, buckthorn: cleaned seeds of *R. alnifolia*, alder buckthorn (**left**) and *R. davurica*, Dahurian buckthorn (**right**).

Good seedcrops for all species are likely to occur in most years. Regeneration of spiny and hollyleaf redberries is primarily by stump-sprouting after fire (Conrad 1987; Keeley 1981).

The reproductive biology of a few non-North American species has been investigated, including (1) the obligatory re-sprouting of *R. palaestina* Boiss. in Israel (Naveh 1974); (2) population sex ratio, flowering phenology, and between-sex differences in reproductive allocation in Italian buckthorn (*R. alaternus* L.), a dioecious shrub of the Mediterranean region (Guitián 1995a); (3) the population sex ratio, pollen-to-ovule ratio, and flowering and fruiting phenology in *R. legionensis* Rothm., a dioecious shrub restricted to limestone areas in the León Province of northwest Spain (Guitian 1995b); and (4) the partitioning of dry mass and nitrogen between flesh and stone in European buckthorn (Lee and others 1991).

Collection, extraction, and storage. Fruits can be collected from the shrubs and trees when ripe, although collection timed to occur about 2 weeks before the fruit is fully ripe may limit losses to birds (Hubbard 1974). Fruits can be

Figure 2—*Rhamnus cathartica*, European buckthorn: longitudinal section through a seed (**left**) and transverse section (**right**) through 4 seeds in a fruit.

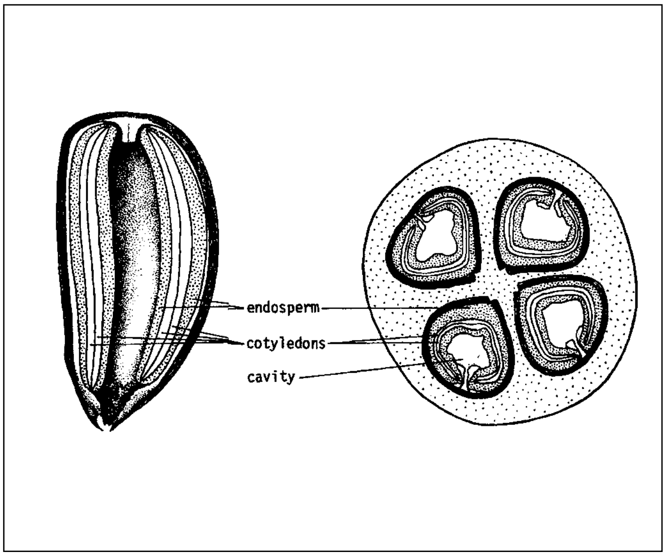
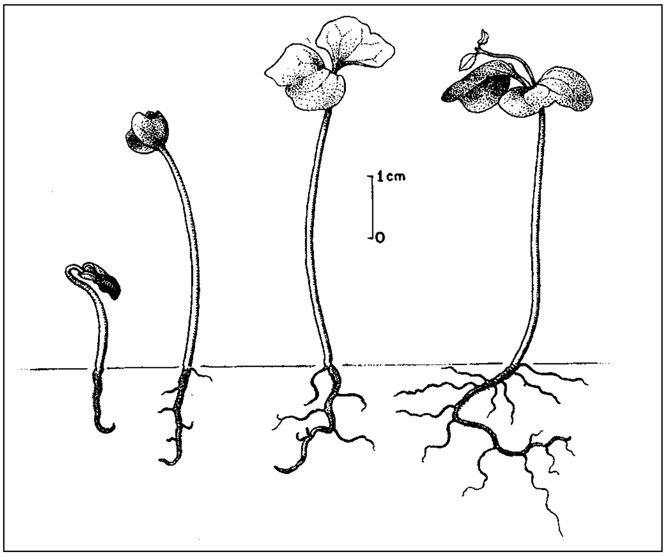


Figure 3—*Rhamnus cathartica*, European buckthorn: seedling development at 1, 4, 19, and 28 days after germination.



run through a macerator with water soon after collection; full seeds can then be cleaned of other material by repeated decantation. Data on yield of seeds are scant and based on limited samples; yields are about 105 seeds/g (2,975 seeds/oz) for spiny redberry (Keeley 1987) and 95 seeds/g (2,690 seeds/oz) for European buckthorn (Lee and others 1991).

Seed storage guidelines have not been developed for buckthorn species, but it appears that seeds can be stored adequately for several years if they are kept in sealed containers at low temperatures (Hubbard 1974).

Pregermination treatment. Considerable variability seems to exist in the need for pregermination treatments of buckthorn seed. Fresh seeds of alder buckthorn and spiny redberry apparently have no innate germination requirements (Hubbard 1974; Keeley 1987). During laboratory tests involving 1 month of stratification at 5 °C, however, more than 75% of the total germination occurred after 7 days of incubation at 23 °C in the dark. Germination increased to 90% when seeds were incubated with an initial heat treatment of 100 °C for 5 minutes and seeds were placed on soil containing 0.5 g powdered charred wood (charate) of the chaparral shrub chamise or greasewood—*Adenostoma fasciculatum* Hook. & Arn.—a treatment designed to simulate conditions after a chaparral fire (Keeley 1987). Seeds of spiny redberry germinated best after 1 month of cold stratification followed by an initial heating treatment of 100 °C for 5 minutes and incubation at 23 °C in charate-enriched soil under a 12-hour photoperiod of 350 $\mu mol/m^2/sec$. Seeds germinated slowly, with more than 75% of the total germination delayed until a second cycle of stratification and incubation (Keeley 1987). Seeds of European buckthorn have been stratified for 2 to 3 months in moist peat at 5 °C (Dirr 1990). Soaking European buckthorn seeds in concentrated sulfuric acid treatment for 20 minutes to break dormancy was found to be harmful (Hubbard 1974).

There are no officially prescribed germination tests procedures for buckthorns. Viability tests by tetrazolium staining have been suggested for European species (Enescu 1991). Seeds should be soaked in water for 24 hours, cracked open in a vise, then re-soaked overnight. Staining should take place in a 1% tetrazolium solution for 24 hours at 30 °C (Dirr 1990). To be considered viable, the embryos must be completely stained, with the exception of the extreme third of the distal ends of the radicle and cotyledons.

Nursery and field practice. Detailed nursery techniques have not been developed for most buckthorn species. The available information suggests that for most of the species, the seeds should be sown in the spring at a depth of 10 to 40 mm (0.4 to 1.6 in) after they have been treated to break dormancy (Hubbard 1974). Germination is epigeal with thin, usually curved cotyledons (figure 3) (Kartesz and Gandhi 1994). Some buckthorns also are propagated by layering and by cuttings or by grafting (Hubbard 1974).