Q

Fagaceae—Beech family

Quercus L.

oak

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Growth habit, occurrence, and use. The oaks—members of the genus *Quercus*—include numerous species of deciduous and evergreen trees and shrubs and make up the single most economically important genus of hardwoods in North America. *Quercus* is also the largest genus of trees native to the United States (Little 1979) and has recently been designated as the "national tree" by the National Arbor Day Foundation. About 500 species are widely distributed throughout the temperate regions of the Northern Hemisphere in both the Eastern and Western Hemispheres as well as southward through Central America to the mountains of Colombia and through Turkey to Pakistan (Sargent 1965). There are about 58 tree and 10 shrub species native to the United States, 104 species in Mexico, and another 30 in Central America and Colombia. At least 70 hybrids have been described, and there are probably many more (Little 1979). Information on hybrids and genetic variation has been summarized for 25 species in Burns and Honkala (1990).

Oaks are divided into 2 subgenera: *Lepidobalanus* (white oaks) and *Erythrobalanus* (black oaks). These subgenera differ in several ways, but most importantly for seed considerations, they differ in time required for fruit maturation, chemical composition of their stored food reserves, and degree of dormancy. In this book, 48 taxa are considered (table 1). Oaks are valuable for a very wide range of products and uses: construction timber, furniture, interior trim, and flooring; watershed protection, wildlife habitat and food, and ornamental plantings; as well as tannins and other extractives and cork. Consequently, many oak species are widely planted for a variety of purposes. For additional information on growth habit, uses, ecology, and silviculture of individual oak species, consult Burns and Honkala (1990).

Flowering and fruiting. Flowering is monoecious. The staminate flowers are borne in clustered aments (catkins) and the pistillate flowers in solitary (or in 2- to many-flowered) spikes in the spring (February to May) before or coincident with emergence of the leaves. Staminate flowers develop primarily from leaf axils of the previous year and range in length from 3 to 35 cm, depending on the species. Pistillate flowers develop from axils of leaves of the current year. The fruit is a nut, commonly called an acorn (figure 1). Acorns of white oaks mature in the year of flowering, whereas acorns of black oaks mature at the end of the second year after flowering (Sargent 1965). Acorns are 1-seeded, or rarely 2-seeded, and occur singly or in clusters of 2 to 5. They are subglobose to oblong, short-pointed at the apex, and partially enclosed by a scaly cup (the modified involucre) at their base. Removal of the cup discloses a circular scar that is often useful in judging acorn maturity. Acorns range in size from 6 mm in length and diameter for willow oak to 50 mm in length and 38 mm in diameter for bur oak (Sargent 1965). Fruits ripen and seeds disperse in the autumn, from late August to early December (Olson 1974; Radford and others 1964; Sargent 1965). The embryo has 2 fleshy cotyledons, and there is no endosperm (figure 2). Acorns are generally green when immature and turn yellow, brown, or black when ripe.

The oaks vary widely in initiation of seed bearing and frequency of large crops (table 2). Acorn production by coppice shoots of chestnut oak only 3 and 7 years old indicates that seed production may start earlier on trees of sprout origin, although coppice sprouts of scarlet and black oaks of comparable ages did not bear seeds (Sharik and others 1983). Environmental factors—such as late spring freezes (Neilson and Wullstein 1980), high humidity during pollination (Wolgast and Stout 1977), or summer droughts (Johnson 1994)—will reduce the acorn crop, but some inherent periodicity seems to exist in many species. Most species produce good crops ("mast years") 1 year out of 3 or 4 (Beck 1977; Christisen and Kearby 1984; Downs and McQuilkin 1944; Goodrum and others 1971). Sork and others (1993) reported good acorn crops in Missouri every 2, 3, and 4 years for black, white, and northern red oaks, respectively. In central California, a study of acorn production in

Figure 1— *Quercus*, oak: acorns of **(top row, left to right)** *Q. alba*, white oak; *Q. falcata*, southern red oak; *Q. kelloggii*, California black oak; *Q. lyrata*, overcup oak. **(second row, left to right)** *Q. macrocarpa*, bur oak; *Q. marilandica*, blackjack oak; *Q. michauxii*, swamp chestnut oak. **(third row, left to right)** *Q. muehlenbergii*, chinkapin oak; *Q. nigra*, water oak; *Q. pagoda*, cherrybark oak; *Q. phellos*, willow oak. **(fourth row, left to right)**, *Q. rubra*, northern red oak; *Q. shumardii*, Shumard oak; *Q. sinuata*, Durand oak; *Q. stellata*, post oak. **(bottom row, left to right)**, *Q. texana*, Nuttall oak; *Q. velutina*, black oak; *Q. wislizeni*, interior live oak.

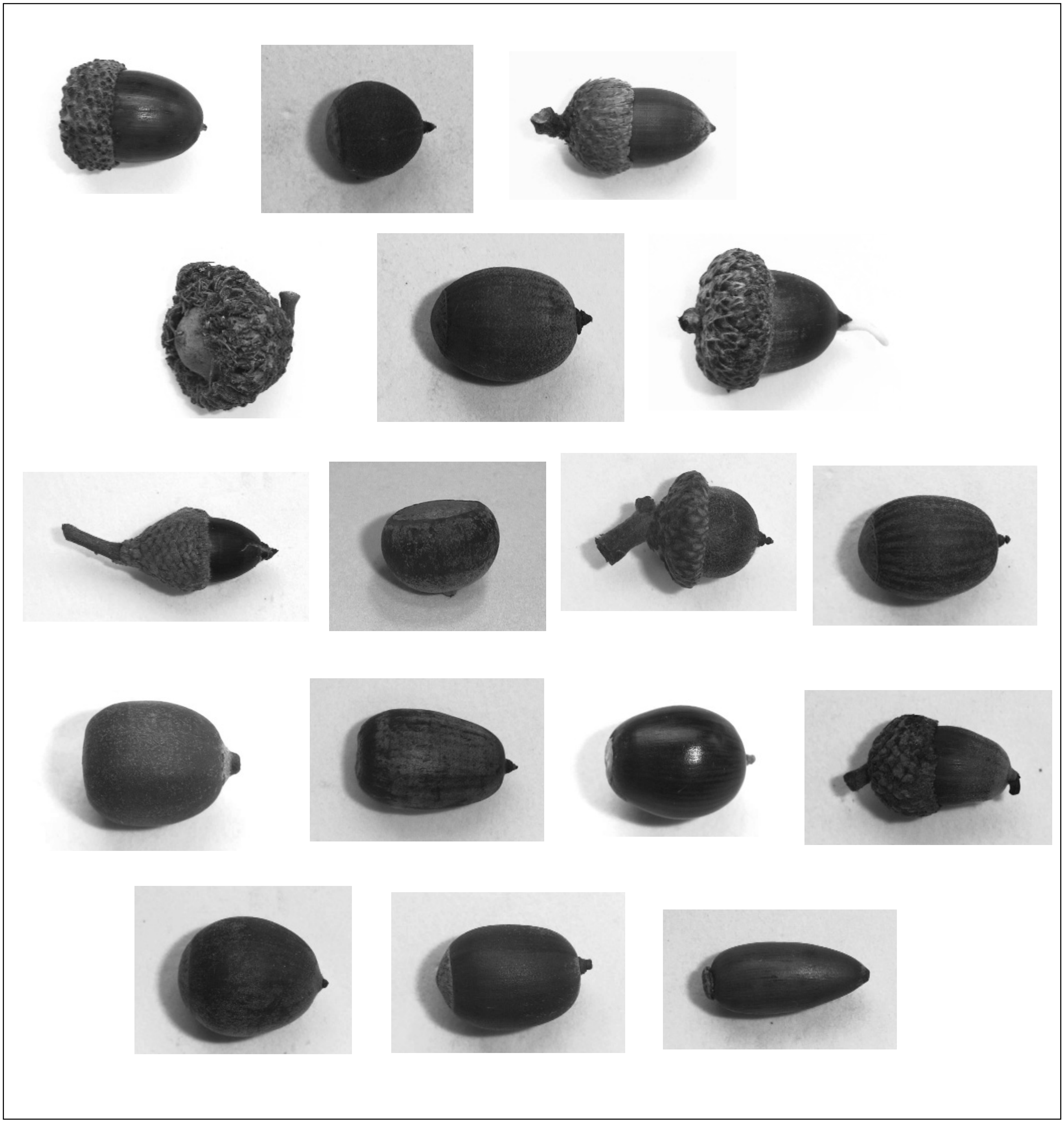


Table 1—*Quercus*, oak: nomenclature and occurrence

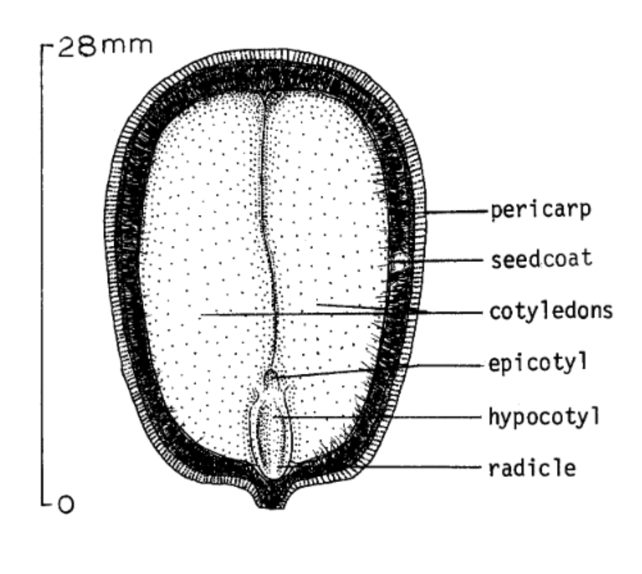
Scientific name & synonym(s)	Group*	Common names	Occurrence
Q. acutissima **Carr.**	white	**sawtooth oak**	E Asia & Japan; introduced to E US
Q. agrifolia **Née**	black	**California live oak,** coast live oak; *encina*	Coastal ranges from central to S California
Q. alba **L.**	white	**white oak,** fork-leaf white & stave oaks	SW Maine to N Wisconsin; S to N Florida & E Texas
Q. arizonica **Sarg.**	white	**Arizona white oak,** Arizona oak; *roble*	SW Texas to New Mexico, Arizona, & N Mexico at 1,500–3,000 m
Q. bicolor **Willd.**	white	**swamp white oak,** cow oak	SW Maine to N Wisconsin S to Tennessee & Missouri
Q. cerris **L.**	white	**European turkey oak,** turkey oak	S Europe to W Asia; introduced to central US
Q. chrysolepis **Liebm.**	white	**canyon live oak,** canyon, maul, goldcup, & live oaks	Mtns of SW Oregon, S to S California & N Mexico; local in mtns. of Nevada & Arizona
Q. coccinea **Muenchh.**	black	**scarlet oak,** black & Spanish oaks	SE Maine to Michigan; S to Georgia, & S Alabama & Missouri
Q. douglasii **Hook. & Arn.**	white	**blue oak,** California blue, iron, & mountain white oaks	Foothills of Sierra Nevada & coastal ranges of California
Q. dumosa **Nutt.**	white	**California scrub oak**, scrub oak	Coast Ranges & offshore islands of California & Baja California
Q. ellipsoidalis **E. J. Hill**	black	**northern pin oak,** black, jack, & Hill oaks	Michigan to SW North Dakota; S to Iowa & NW Ohio
Q. emoryi **Torr.**	black	**Emory oak,** black oak, *bellota, roble negro*	Mtns of Trans-Pecos Texas, SW New Mexico, SE & central Arizona, & N Mexico
Q. falcata **Michx.** *Q. triloba* Michx.	black	**southern red oak,** Spanish & red oaks	SE New York to S Missouri; S to N Florida & SE Texas
Q. gambelii **Nutt.** *Q. vreelandii* Rydb. *Q. utahensis* (A. DC.) Rydb.	white	**Gambel oak,** Rocky Mtn. white & Utah white oaks; *encino*	Colorado and Wyoming, W to Utah & S to Arizona, New Mexico, Texas, & NW Oklahoma
Q. garryana **Dougl. ex Hook.**	white	**Oregon white oak,** Garry, post, Oregon, Brewer, & shin oaks	British Columbia; S in mtns to central California
Q. grisea **Liebm.**	white	**gray oak**	SW Texas to New Mexico, Arizona, & N Mexico
Q. ilicifolia **Wangenh.**	black	**bear oak,** scrub oak	S Maine, W to New York; S to West Virginia, SW Virginia, & W North Carolina
Q. imbricaria **Michx.**	black	**shingle oak,** laurel oak	Pennsylvania, S to S Michigan; North Carolina & Arkansas; local in Louisiana & Alabama
Q. incana **Bartr.**	black	**bluejack oak,** sandjack, bluejack, shin, & turkey oaks	Coastal plain from Virginia to central Florida; W to Louisiana, E Texas, Oklahoma, & Arkansas
Q. kelloggii **Newb.**	black	**California black oak,** black & Kellogg oaks	SW Oregon; S through Coast Ranges & Sierra Nevada to S California
Q. laevis **Walt.** *Q. catesbaei* Michx.	black	**turkey oak,** scrub & Catesby oaks	Coastal plain from SE Virginia to central Florida, & W to Louisiana
Q. laurifolia **Michx.**	black	**laurel oak,** Darlington, water, swamp, laurel, & diamond-leaf oaks	Coastal plain from SE Virginia to S Florida; W to E Texas & S Arkansas
Q. lobata **Née**	white	**California white oak,** valley, valley white, weeping, & water oaks; *roble*	Valleys & foothills in California; also Santa Cruz & Santa Catalina Islands
Q. lyrata **Walt.**	white	**overcup oak,** swamp post, water white, & swamp white oaks	Coastal plain from Delaware to Florida; W to E Texas & SW Indiana
Q. macrocarpa **Michx.**	white	**bur oak,** mossycup, blue oak, mossy-overcup, & scrub oaks	S New Brunswick & Manitoba; S to Tennessee & SE Texas

Table 1—*Quercus,* oak: nomenclature and occurrence (continued)

Scientific name & synonym(s)	Group*	Common names	Occurrence
***Q. marilandica* Muenchh.**	black	**blackjack oak,** barren & jack oaks; blackjack	New York, W to Ohio, Iowa, & Oklahoma; S to Texas & NW Florida
***Q. michauxii* Nutt.** *Q. prinus* L.	white	**swamp chestnut oak**, cow & basket oaks	Coastal plain from New Jersey to N Florida; W to E Texas; N in Mississippi Valley to S Illinois & Indiana
***Q. muehlenbergii* Engelm.**	white	**chinkapin oak**, rock, yellow, chestnut, yellow chestnut, & rock chestnut oaks	W Vermont & New York to Minnesota & SE Nebraska; S to NW Florida & central Texas
***Q. nigra* L.**	black	**water oak,** possum oak	Coastal plain from New Jersey to S Florida, W & spotted oaks to E Texas, & N in Mississippi Valley to SE Oklahoma
***Q. pagoda* Raf.** *Q. falcata* var *pagodaefolia* Ell.	black	**cherrybark oak,** bottomland red, Elliott, & swamp red oaks	SE New Jersey to E Oklahoma; S to N Florida & E Texas
***Q. palustris* Muenchh.**	black	**pin oak,** swamp, water, Spanish, & swamp Spanish oaks	Massachusetts & Vermont to S Michigan; S to NE Oklahoma, Tennessee, & central North Carolina
***Q. petraea* (Mattusch) Liebl.** *Q. sessiliflora* Salisb.	white	**durmast oak**, sessile oak	Europe & W Asia; planted in central & NE US
***Q. phellos* L.**	black	**willow oak**, pin, peach, & swamp willow oaks	Coastal plain from New Jersey to N Florida; W to E Texas & S Illinois
***Q. prinus* L.** *Q. montana* Willd.	white	**chestnut oak,** rock chestnut, rock, & tanbark oaks	SW Maine & S Ontario; S to central Georgia & NW Mississippi
***Q. robur* L.**	white	**English oak**, pedunculate oak	Europe, N Africa, & W Asia; naturalized in SE Canada & NE US
***Q. rubra* L.** *Q. borealis* Michx.f.	black	**northern red oak**, red, common red, eastern red, & gray oaks	Cape Breton Island & Nova Scotia; W to Ontario & S to eastern Oklahoma & Georgia
***Q. shumardii* Buckl.**	black	**Shumard oak,** spotted, Schneck, swamp red, & Shumard red oaks	Coastal plain, mostly, from North Carolina to N Florida; W to central Texas, Kansas, & S Illinois
***Q. sinuata* Walt.** *Q. durandii* Buckl.	white	**Durand oak,** Durand white, bluff, & bastard oaks	Coastal Plain from North Carolina to N Florida & W to Texas, Oklahoma, & NE Mexico
***Q. stellata* Wangenh.**	white	**post oak,** iron oak	SE Massachusetts to SE Iowa, & S to central Florida & Texas
***Q. suber* L.**	white	**cork oak**	SW Europe & N Africa; planted in California
***Q. texana* Buckl.** *Q. nuttallii* Palmer	black	**Nuttall oak**, red, Red River, & pin oak	Gulf coastal plain from Alabama to SE Texas; N in Mississippi Valley to SE Missouri
***Q. turbinella* Greene**	white	**shrub live oak,** turbinella & scrub oaks; *encino*	SW Colorado & Utah; S to S California, Arizona, & northern Mexico
***Q. turbinella* var. *ajoensis* (C.H. Muller) Little**	white	**shrub live oak,** Ajo oak	SW Arizona & N Mexico
***Q. vaccinifolia* Kellog**	white	**huckleberry oak**	SW Oregon to central California
***Q. variabilis* Bl.** *Q. chinensis* Bge.[not Abel] *Q. serrata* Carruth. [not Thunb.]	black	**oriental oak**	N China, Korea, & Japan; planted in central & NE US
***Q. velutina* Lam.**	black	**black oak**, yellow, smooth-bark, quercitron, & yellow-bark oak; *quercitron*	SW Maine to SE Minnesota; S to N Florida & E Texas
***Q. virginiana* P. Mill.**	white	**live oak**, Virginia live oak; *encino*	Coastal plain from SE Virginia to S Florida (including Florida Keys); W to S Texas
***Q. wislizenii* A. DC.**	black	**interior live oak**, highland live & Sierra live oaks	Foothills of Sierra Nevada & Coast Ranges in California, S to Mexico

Sources: Little (1979), Olson (1974), Sargent (1965).
* White oaks belong to subgenus *Lepidobalanus;* black oaks belong to subgenus *Erythrobalanus*.

Figure 2—*Quercus rubra,* northern red oak: longitudinal section through a seed.



valley, blue, and California black oaks and canyon live and coast live oaks (Koenig and others 1994) found no mast production patterns at the population level. Crop failures did occur frequently but they were probably more related to lack of pollination and fertilization success than to inherent patterns. Cecich (1993) concluded that most of the potential seedcrop in oaks in Missouri is lost when pistillate flowers abort between the time of pollination and fertilization. Really good crops of California black oak acorns were found to occur only every 8 years or so (McDonald 1992). The following yield averages on an area basis have been reported: 3.2 to 1,620 kg/ha (2.9 to 1,448 lb/ac) for white oak in Illinois (Johnson 1975); 208 kg/ha (186 lb/ac) for southern Appalachian oaks (Beck 1977); and 560 kg/ha (500 lb/ac) for Oregon white oak in California (Stein 1990).

Collection and cleaning of acorns. Collecting acorns of high quality requires an awareness of the indices of acorn maturity. Natural dissemination from the tree is a sure sign of maturity, of course, but collections are often made before this time to reduce losses to deer, rodents, and other predators that quickly eat fallen acorns. Good indices of maturity for most species are (1) change in pericarp color from green to yellow, brown, or black; (2) a cup scar colored pink, lemon, orange, or white; and (3) cups that slip easily from the acorns without resistance (Bonner and Vozzo 1987; Lotti 1959). Ripe acorns may be collected from August to December from the ground or they can be shaken from trees onto canvas or plastic sheets after ripening. Mechanical tree shakers can be very effective with oaks where the terrain or stand conditions permit it. Collecting acorns from downed trees in logging operations also can be successful if the trees were cut after the acorns matured. Acorns should be collected from the ground within a few days after dispersal to avoid losses to predators, desiccation of the acorns, and early germination of the non-dormant species (primarily the white oaks). California black oak also requires prompt collection because mold often infects fallen acorns (McDonald 1990).

To avoid desiccation, which can quickly reduce acorn quality, acorns should be floated in water after collection, preferably at the end of each collection day. This action will maintain high moisture contents and permit removal of trash and unsound acorns. Sound acorns will sink and the other material will float. For acorns collected from the ground, moisture conditions at time of collection can affect the flotation process. If the ground is very dry, many good acorns may float initially, and the lot may have to stay in the water overnight to allow sound acorns enough time to take up moisture and sink. In contrast, when the ground is wet, many unsound acorns may be heavy enough to sink in water, and a few hours of drying at ambient temperature can help the separation. Water flotation is never 100% effective, but common sense and attention to detail will enable collectors to make dramatic improvements in the quality of their acorns. Another way to allow for different acorn moisture conditions may be to use salt solutions to change the density of the water. In a test with water oak and willow oak (Johnson 1983), 230 g of salt/liter of water for unsaturated acorns and 285 g/liter for saturated acorns, led to recovery of up to 11% more good acorns. The acorns were not in the salt solutions long enough to take up the chemical, and a quick rinse after recovery removed surface salt. In the dry climate of California, acorns of blue oak dry so quickly that collection directly from the tree may be the only way to ensure seed quality (McCreary and Koukoura 1990). A loss of only 10% acorn moisture resulted in almost 40% less germination for blue oak.

Data on acorn size and weight are summarized in table 3. For many years, nurseries did little sizing of acorns, but now that is changing, at least in the South. Numerous nurseries now size acorns with screens or other devices (Bonner and Vozzo 1987) to gain in uniformity of germination and bed density. Positive correlations between acorn size and leaf area have been reported for northern red, chestnut, white, and bear oaks (Farmer 1980) and also between acorn size and shoot growth for English and durmast oaks (Kleinschmit and Svolba 1979).

In years when light crops are produced, the percentage of acorns that are infested with insect larvae will be large,

Table 2—*Quercus,* oak: height, seed-bearing age, and seedcrop frequency

Species	Height at maturity (m)	Year first cultivated	Minimum seed-bearing age (yrs)	Years between large seedcrops
Q. acutissima	15	1862	5	—
Q. agrifolia	23	1849	15	—
Q. alba	30	1724	20	4–10
Q. arizonica	12	—	—	—
Q. bicolor	30	1800	20	3–5
Q. cerris	30	1735	—	—
Q. chrysolepis	30	1877	20	2–4
Q. coccinea	30	1691	20	3–5
Q. douglasii	18	—	—	2–3
Q. dumosa	6	—	—	—
Q. ellipsoidalis	21	1902	—	2–4
Q. emoryi	18	—	—	—
Q. falcata	27	1763	25	1–2
Q. gambelii	15	—	—	—
Q. garryana	21	1873	—	2–3
Q. grisea	20	—	—	—
Q. ilicifolia	6	1800	—	—
Q. imbricaria	21	1724	25	2–4
Q. incana	12	—	—	—
Q. kelloggii	26	1878	30	2–3
Q. laevis	9	1834	—	1–2
Q. laurifolia	27	1786	15	1
Q. lobata	30	1874	—	2–3
Q. lyrata	24	1786	25	3–4
Q. macrocarpa	30	1811	35	2–3
Q. marilandica	15	—	—	—
Q. michauxii	30	1737	20	3–5
Q. muehlenbergii	24	1822	—	—
Q. nigra	24	1723	20	1–2
Q. pagoda	34	1904	25	1–2
Q. palustris	24	1770	20	1–2
Q. petraea	30	Long	40	5–7
Q. phellos	30	1723	20	1
Q. prinus	24	1688	20	2–3
Q. robur	34	Long	20	2–4
Q. rubra	30	1724	25	3–5
Q. shumardii	34	1907	25	2–3
Q. sinuata	23	—	—	—
Q. stellata	18	1819	25	2–3
Q. suber	24	1699	12	2–4
Q. texana	30	1923	5	3–4
Q. turbinella	3	—	—	3–5
Q. vaccinifolia	1	1895	—	—
Q. variabilis	24	1861	—	2
Q. velutina	27	1905	20	2–3
Q. virginiana	18	1739	—	1
Q. wislizenii	18	1874	—	5–7

Sources: Burns and Honkala (1990), Olson (1974), Sargent (1965), Smith (1993), Sork and others (1993), Vines (1960).

and flotation offers a simple way to remove these damaged acorns. The major insect pests of acorns in the United States are the acorn weevils (*Curculio* spp.), filbertworms (*Melissopus latiferranus* Walsingham), and acorn moths (*Valentinia* spp.) (Baker 1972; Gibson 1972, 1982; Oliver and Chapin 1984; Vozzo 1984). A cynipid wasp that causes galls on acorns of European turkey oak and English oak is a major pest in Europe, causing 30 to 50% losses of the acorn crop each year in the United Kingdom (Collins and others 1983). Prevention of infestation is not possible, so infested acorns must be removed from the lots. Some collectors kill the larvae of acorn weevils by immersing the acorns in hot water (48 °C) for 40 minutes (Olson 1974). This temperature is dangerously close to conditions that will damage the

Table 3—*Quercus*, oak: seed yield data

	Seed weight/ fruit vol		Cleaned seeds/weight				
			Range		Average		
Species	kg/hl	lb/bu	/kg	/lb	/kg	/lb	Samples
Q. acutissima	—	—	210–245	95–110	85	187	2
Q. agrifolia	—	—	—	—	200	440	1
Q. alba	58–129	45–100	155–465	70–210	98	215	23
Q. bicolor	—	—	200–385	90–175	265	120	3
Q. cerris	—	—	130–320	60–145	240	110	4
Q. chrysolepis	—	—	110–310	50–150	—	—	—
Q. coccinea	39–77	30–60	230–890	105–405	520	235	4
Q. douglasii	—	—	120–330	55–180	220	100	4
Q. dumosa	—	—	—	—	220	100	1
Q. ellipsoidalis	—	—	450–640	205–290	540	245	11
Q. falcata	42–64	33–50	705–1,730	320–785	1,190	540	9
Q. garryana	50	39	165–220	75–100	185	85	3
Q. ilicifolia	—	—	—	—	1545	700	1
Q. imbricaria	—	—	695–1,750	315–795	915	415	11
Q. incana	—	—	500–1,500	225–680	—	—	—
Q. kelloggii	—	—	115–325	52–145	210	95	49
Q. laevis	—	—	—	—	870	395	1
Q. laurifolia	—	—	860–1,520	90–690	1,235	560	3
Q. lobata	—	—	165–525	75–237	285	130	4
Q. lyrata	—	—	285–340	130–154	265	120	6
Q. macrocarpa	39–45	30–35	90–300	40–135	165	75	8
Q. michauxii	51–80	40–62	75–430	35–195	125	55	35
Q. muehlenbergii	60–66	47–51	580–1,145	265–520	870	395	4
Q. nigra	57–72	44–56	510–1,545	230–700	640	290	226
Q. pagoda	—	—	925–1,640	420–745	690	312	41
Q. palustris	—	—	705–1,190	320–540	475	220	33
Q. petraea	—	—	130–650	60–295	375	170	9
Q. phellos	59–60	46–47	600–1,530	270–695	835	380	183
Q. prinus	—	—	120–430	55–195	220	100	5
Q. robur	—	—	200–495	90–225	285	130	10
Q. rubra	28–134	22–104	165–565	75–255	235	105	55
Q. shumardii	64	50	170–280	80–130	220	100	27
Q. sinuata	53	47	—	—	6,400	290	1
Q. stellata	69	54	440–1,400	200–635	840	380	9
Q. suber	—	—	110–220	50–100	165	75	13
Q. texana	67	52	125–315	55–145	220	100	83
Q. turbinella	—	—	660–770	300–350	715	325	2
Q. vaccinifolia	33	26	1630–2,910	740–1,320	2,270	1,030	2
Q. variabilis	—	—	165–275	75–125	230	105	12
Q. velutina	53–63	41–49	275–882	125–400	540	245	7
Q. virginiana	71	55	530–1,125	240–510	775	350	4
Q. wislizenii	36	28	100–152	100–150	275	125	3

Sources: Burns and Honkala (1990), Olson (1974), Toumey and Korstian (1942), Van Dersal (1938).

acorns, however, so caution must be used. In a study with live oak, germination and seedling growth dropped dramatically after hot water treatments of 7.5 to 60 minutes (Crocker and others 1988). Because none of these insects attacks other acorns during storage, the infestation cannot spread. Only in cases of exporting acorns to other countries where seed health regulations require treatment would this treatment be completely justified.

Storage. Acorns are recalcitrant seeds; they cannot tolerate desiccation below a rather high minimum moisture content and are therefore very difficult to store. Oaks are by far the most commercially important group of recalcitrant species in the temperate zone. The lethal moisture contents vary by species, but range from 15 to 20% in black oaks and 25 to 30% in white oaks. Most species of the black oak group can be stored for 3 years by maintaining high acorn moisture levels (above 30%) and storing just above freezing (1 to 3 °C) in containers that allow some gas exchange with the surrounding atmosphere (Bonner 1973; Bonner and Vozzo 1987; Suszka and Tylkowski 1982). Most species will germinate in storage under these conditions, but pre-sprouting does not prevent sowing or production of plantable seedlings (Bonner 1982). White oak acorns can be stored in a similar fashion, but safe moisture levels are 45 to 50%. White oaks germinate in storage much more readily than black oaks, and do not survive as well. As a practical matter, storage of white oak acorns for more than 6 months is seldom attempted in this country. Acorns of English oak have been successfully stored for 3 years in Europe by lowering the moisture levels slightly and mixing them with dry sawdust or peat (Suszka and Tylkowski 1980). Acorns of the same species are routinely stored for 3 years in Denmark also by lowering the moisture content slightly and storing the acorns right at freezing in open containers with no medium. In the case of another white oak, partial drying of California scrub oak acorns significantly improved viability retention over 8 months (Plumb and McDonald 1981). The partial drying may be beneficial because it reduces the incidence of fungi on the surface of the acorns.

Acorns can be stored in plastic bags, drums, or even boxes as long as the containers are not completely sealed and the acorns do not get too dry. Some European species can be stored by immersion in water (Jones 1958), and Nuttall oak has been successfully stored overwinter submerged in water at 3 to 5 °C (Johnson 1979). If drums or boxes are used, it is wise to insert a plastic bag liner. Respiration is rapid in seeds with high moisture levels, and oxygen will be depleted and carbon dioxide increased dramatically in just a few weeks. Plastic bags at least 4 mils thick are useful for storage; tops should be loosely folded over, not sealed. There is some evidence that white oaks should be stored in thinner bags (1.75 mils) because of their greater requirement for oxygen (Rink and Williams 1984). Most species can actually tolerate temperatures a few degrees below freezing (Suszka and Tylkowski 1980), but storage below –5 °C is usually fatal.

Pregermination treatment. Acorns of the white oak group generally have little or no dormancy and will germinate almost immediately after falling. These species should usually be planted in the fall. They will quickly put down radicles, but epicotyl dormancy occurs in some species and prevents shoot growth until the following spring. Epicotyl dormancy has been noted in English oak (Wigston 1987) and in eastern and southern white and chestnut oaks (Farmer 1977). White oaks in the warmer climate of California—coast and canyon live oaks, and blue, California scrub, and valley oaks—apparently do not have epicotyl dormancy (Matsuda and McBride 1989). Acorns of bur oak from the northern portion of its range actually require 60 days of cold, moist stratification for prompt germination (Tinus 1980). Acorns of the black oak group exhibit variable dormancy that is apparently imposed by the pericarp, the embryo, or both (Hopper and others 1985; Jones and Brown 1966; Peterson 1983), and stratification is usually recommended before spring-sowing or certain types of germination tests. Epicotyl dormancy has been reported in at least 1 black oak species—bear oak (Allen and Farmer 1977). If proper procedures are followed for storage of black oak acorns, the storage conditions will also serve to complete the stratification requirement, and additional treatment is not necessary (Bonner and Vozzo 1987). If additional stratification is needed, imbibed acorns should be held for 4 to 12 weeks at temperatures of 2 to 5 °C. The acorns may be mixed with peat or other media, but this is not necessary. Most managers stratify in plastic bags without medium, turning the bags each week or so to prevent pooling of excess moisture in the bags (Bonner and Vozzo 1987). Acorns of the black oak group sown in the fall or early winter need not be stratified before to sowing.

Germination tests. In the standard official laboratory test procedure for all oaks, the acorns should be soaked in water for 48 hours; then a third of the acorn at the cup scar end should be cut off and the pericarp removed from the top half and placed on thick, moist blotters at alternating temperatures of 20 to 30 °C (ISTA 1993). No other pretreatments are necessary, and germination should be complete within 14 days. Germination can also be tested with intact acorns in sand, peat, or other media in greenhouse flats. In such tests, stratification may be necessary for black oak species (table 4). Germination is hypogeal (figure 3) and is generally complete in 3 to 5 weeks. Rapid estimates of viability can also be made with cutting tests, radiography, or tetrazolium staining (Belcher and Vozzo 1979; Bonner and Vozzo 1987). Cutting tests are reliable on freshly collected acorns, and radiography is very good for quick determination of insect infestation. Tetrazolium staining can also provide information on seed vigor, but acorn chemistry and morphology present some problems in this test (Bonner 1984).

Nursery practice. Numerous research studies have shown that success in planting oaks depends on production of vigorous seedlings through low sowing densities and undercutting in the beds (Schultz and Thompson 1990). Container production in greenhouses is also practiced for a few species (Tinus 1980). Fall-sowing acorns is preferable to spring-sowing in many instances if weather allows bed preparation in the fall. Fall-sowing eliminates the need for a large storage capacity for acorns and avoids the problems of fungi and early germination in storage. One disadvantage to

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

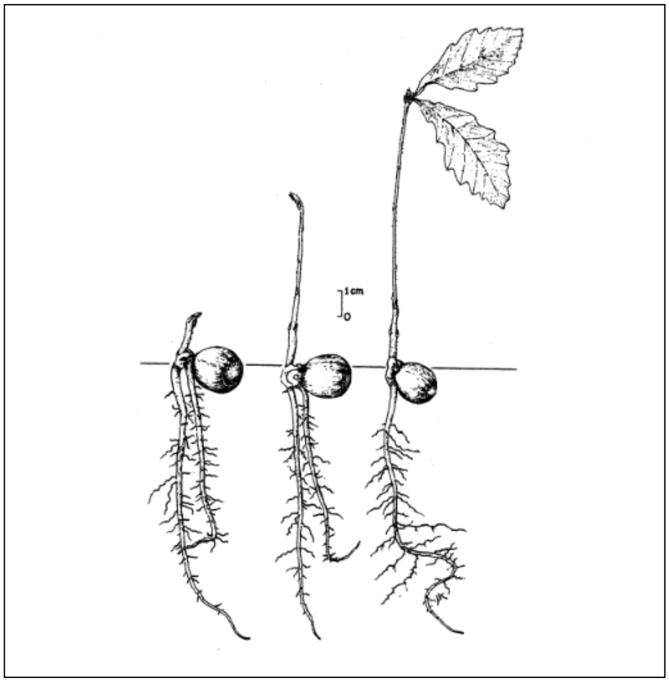
Species	Cold stratification (days)	Germination test conditions: Medium	Temp (°C): Day	Temp (°C): Night	Day	Germinative rate: Avg (%)	Germinative rate: Days	Germination: (%)	Germination: Samples
Q. acutissima	—	—	—	—	—	—	—	98	1
Q. agrifolia	0	—	—	—	15–40	—	—	73	1
Q. alba	0	Kimpac	30	20	30–98	39–93	10–41	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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