Betulaceae—Birch family

Carpinus L.

hornbeam or ironwood

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Growth habit, occurrence, and use. The hornbeam genus—*Carpinus* L.—includes about 35 species of deciduous, monoecious, small to large trees, that are native to the Northern Hemisphere from Europe to eastern Asia, south to the Himalayas, and in North and Central America (Furlow 1990; Hillier 1991; Krüssmann 1984; LHBH 1976; Suszka and others 1996). Five species are considered here (table 1). Hornbeams occur mainly as understory trees in rich, moist soils on bottomlands and on protected slopes (Metzger 1990; Rudolf and Phipps 1974). European hornbeam is an important forest tree species throughout Europe (Furlow 1990). In Mexico and Central America, *Carpinus tropicalis* (J.D. Sm.) Lundell forms a dominant canopy component (Furlow 1990). American hornbeams, which are native to the eastern United States and Canada, are smaller trees that grow in the mixed hardwood forest understory (Furlow 1990; Metzger 1990). Several geographic races of American hornbeam exist in North America (Fernald 1935; Furlow 1990). The races are morphologically variable and difficult to distinguish on the basis of independent characters. Furlow (1987a), using multivariate analysis, analyzed this geographical variation. The northern American hornbeam species is divided into the subsp. *caroliniana* from along the Atlantic and Gulf Coastal Plains of the southeastern United States and the subsp. *virginiana* of the Appalachian Mountains and northern interior regions to the West (Furlow 1987b). The Latin American *C. tropicalis* is divided into subsp. *tropicalis* of the highlands of southern Mexico and north Central America and subsp. *mexicana* of the mountains in northeastern Mexico and the trans-Mexican volcanic belt (Furlow 1987b).

The wood of hornbeams is extremely hard—hence the common name "ironwood"—and is used for making tool handles and mallet heads. It is also used to produce the high-quality charcoal used in gunpowder manufacture (Bugala 1993; Furlow 1990). Species of ornamental interest in the United States are listed in table 1. Most of the information presented in this chapter deals with European and American hornbeams, unless noted otherwise.

European hornbeam is a slow-growing tree (about 3 m over 10 years) that is pyramidal in youth but oval-rounded to rounded at maturity (Dirr 1990; Suszka and others 1996). This species is planted in the landscape as single specimen trees or as screens or hedges. It tolerates a wide range of soil and light conditions but grows and develops best in full sun on rich, moist sites with good drainage (Dirr 1990; Metzger 1990). Several cultivars produce excellent color, form, and texture. The cultivar 'Fastigiata' is the most common one in cultivation, with foliage more uniformly distributed along the branches than on other cultivars (Dirr 1990; Hillier

Table 1—*Carpinus,* hornbeam: nomenclature, occurrence, height at maturity, and date of first cultivation

Scientific name	Common name(s)	Occurrence	Height at maturity (m)	Year first cultivated
***C. betulus* L.**	**European hornbeam**	Europe, Asia Minor, & SE England	12–21	1800s
***C. caroliniana* Walt.**	**American hornbeam,** musclewood, blue beech, ironwood	Nova Scotia S to Florida, W to Texas, & N to Minnesota & Ontario; also in central & S Mexico & Central America	6–9	1812
***C. cordata* Blume**	**heartleaf hornbeam**	Japan, NE Asia, & China	6–15	1879
***C. japonica* Blume**	**Japanese hornbeam**	Japan	6–9	1895
***C. orientalis* Mill.**	**Oriental hornbeam**	SE Europe & SW Asia	6–8	1739

Sources: Dirr (1990), Hillier (1991), Krüssmann (1984), LHBH (1976), Metzger (1990).

1991; Krüssmann 1984). This cultivar is used primarily as a screen hedge because of its dense, compact, ascending branches (Dirr 1990). The bark on older trees is gray and beautifully fluted.

American hornbeam is a small, multi-stemmed, bushy shrub or single-stemmed tree with a wide-spreading, flat or round-topped crown, that grows slowly; averaging 2.5 to 3 m over a 10-year period (Dirr 1990; Metzger 1990). This species has considerable fall color variation, from yellow to orange-red, and is planted in the landscape in groups or as an understory tree (Beckett 1994; Dirr 1990). The bark on older trees is slate gray, smooth, and irregularly fluted; the overall appearance is comparable to the flexed bicep and forearm muscles—hence another common name, "muscle-wood" (Dirr 1990).

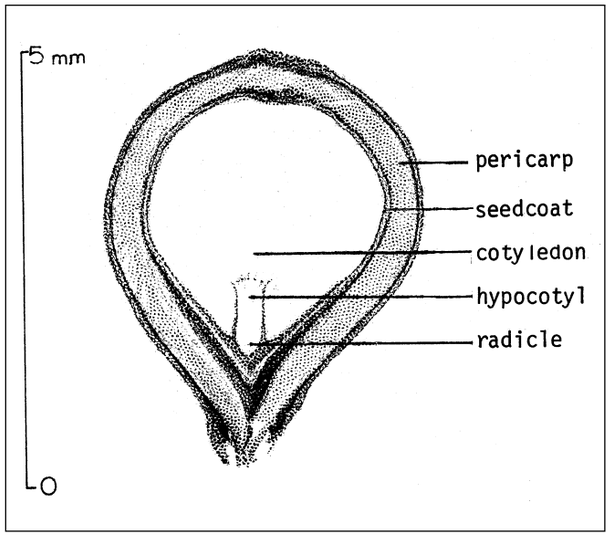
Heartleaf hornbeam is a small tree of rounded habit with leaves that are large with deeply heart-shaped bases, and with large, rich brown winter buds (Dirr 1990; Hillier 1991; Krüssmann 1984). The bark is slightly furrowed and scaly (Dirr 1990). The fruits are borne in cigar-shaped catkins (Dirr 1990). Japanese hornbeam is a wide-spreading small tree or large shrub with prominently corrugated leaves and with branches that radiate like the ribs on a fan (Dirr 1990; Hillier 1991). Oriental hornbeam grows as a large shrub or small tree with an overall U-shaped branching pattern (Dirr 1990). The bracts of this species are unlobed, differentiating it from European and American hornbeams (Dirr 1990). The main branches and stems are twisted, giving this species an interesting winter appearance (Dirr 1990).

Flowering and fruiting. In most species, the staminate and pistillate catkins appear in the spring concurrently as the trees are leafing out (Dirr 1990; Furlow 1990; Metzger 1990; Suszka and others 1996). The fruits are ovoid, ribbed, single-seeded nutlets (figures 1 and 2), each borne at the base of a distinctive 3-lobed involucre (bract) (Metzger 1990; Rudolf and Phipps 1974). The fruits ripen from late summer to fall. They are dispersed from fall to spring and are carried only a short distance by the wind or may be dispersed farther by birds (Rudolf and Phipps 1974). Details of flowering and seeding habits for European and American hornbeams are described in tables 2 and 3.

Collection of fruits; extraction, cleaning, and storage of seeds. Fruits harvested while they are still green (when the wings are turning yellow and are still soft and pliable) can be fall-sown for germination the following spring (Bugala 1993; Dirr 1990; Hartmann and others 1990). These seeds should not be allowed to dry out, as a hard seedcoat will develop, and they should be checked before sowing for the presence of well-developed embryos (Bugala 1993;

Figure 1—*Carpinus caroliniana*, American hornbeam: nutlet with involucre removed

Figure 2—*Carpinus caroliniana*, American hornbeam: longitudinal section through a nutlet.



Leiss 1985). Green seeds can also be stratified for 3 to 4 months over winter and sown the following spring (Hartmann and others 1990).

Mature seeds (with hardened seedcoats) should be collected, spread out in thin layers in a cool, well-aerated room or shed, and allowed to dry superficially (Macdonald 1986; Rudolf and Phipps 1974; Suszka and others 1996). The bracts do not need to be removed if the seeds are to be broadcast (Macdonald 1986). They should be removed, however, from large quantities of seeds (to aid in mechanical sowing) by placing the seeds in a de-winging machine or beating the seeds in bags (Rudolf and Phipps 1974; Suszka

Table 2—*Carpinus,* carpinus: phenology of flowering and fruiting

Species	Location	Flowering	Fruit ripening	Seed dispersal
C. betulus	Europe & NE US	Apr–May	Aug–Nov	Nov–spring
C. caroliniana	NE US	Mar–June	Aug–Oct	Nov–spring

Source: Rudolf and Phipps (1974).

Table 3—*Carpinus,* hornbeam: seed-bearing age, seedcrop frequency, seed weight, and fruit ripeness criteria

Species	Minimum seed-bearing age (yrs)	Years between large seedcrops	Average no. cleaned seeds /kg	Average no. cleaned seeds /lb	Preripe color	Ripe color
C. betulus	10–30	1–2	28,660	13,000	Green	Brown
C. caroliniana	15	3–5	66,138	30,000	Green	Greenish brown

Sources: Allen (1995), Rudolf and Phipps (1974).

and others 1966). The debris can be removed from seedlots by screening and fanning (Macdonald 1986). European hornbeam seeds with bracts weigh 15 to 18 kg/0.35 hl (33 to 40 lb/bu). Fruits weighing 45 kg (100 lb) yield about 23 kg (50 lb) of cleaned seed (Rudolf and Phipps 1974). The average numbers of cleaned seeds per weight of European and American hornbeam are listed in table 3.

Hornbeam seeds stratified immediately after extraction can be stored up to 2 years (Rudolf and Phipps 1974). European hornbeam seeds in nuts partially dried to 8 to 10% moisture content can be stored in sealed containers at a temperature of –3 °C for at least 5 years (Bugala 1993). Seeds of this species stored at 10% moisture content in sealed containers at 3 °C lost no viability after 14 months (Suszka and others 1969).

Pregermination treatments. Hornbeam seeds that are allowed to mature and become dry will develop a hard seedcoat. Dormancy, caused by conditions in the embryo and endosperm, may be overcome by stratification treatments (a warm period followed by a cold period). In general, 1 to 2 months of warm stratification followed by 2 to 3 months of cold stratification are necessary to break dormancy of the European hornbeam. The International Seed Testing Association (1993) prescribes 1 month of moist incubation at 20 °C, followed by 4 months at 3 to 5 °C, for laboratory testing of European hornbeam. Results of stratification treatments vary for different species of hornbeam, so several are presented in table 4. Bretzloff and Pellet (1979) reported that gibberellic acid treatment at 0.025, 0.1, and 0.5 g/liter (25, 100, and 500 ppm) generally increased germination of American hornbeam seeds stratified at 4 °C for 6, 12, or 18 weeks, compared to stratification alone. Scarification of the seedcoat plus gibberellic acid also improved germination (Bretzloff and Pellet 1979). Gordon and others (1991) and Suszka and others (1996) provide extensive information on the sampling, seed pretreatment, purity, viability, and germination testing, seedling evaluation, and storage of forest tree and shrub seeds. Specific procedures are presented for a number of species.

Germination tests. Germination percentage of stratified seeds is low, usually less than 60% and occasionally as low as 1 to 5% (Metzger 1990). Germination tests may be made on pretreated seeds in germinators, or in flats of sand, or sand plus peat (Rudolf and Phipps 1974). Viability of European and American hornbeams is best determined by using the tetrazolium test for viability (Chavagnat 1978; Gordon and others 1991; ISTA 1993; Suszka and others 1996). Details of germination test results are shown in table 5. Germination of hornbeam seeds is epigeal.

Nursery practice and seedling care. The optimum seedbed is continuously moist, rich loamy soil protected from extreme atmospheric changes (Rudolf and Phipps 1974; Suszka and others 1966). Germination of many naturally disseminated seeds is delayed until the second spring after seed dispersal (Rudolf and Phipps 1974). If germination is expected the first spring, seeds should be collected while they are still green (the wings turning yellow and still soft and pliable) and sown in the fall, or stratified immediately and sown the following spring (Bugala 1993; Dirr 1990; Hartmann and others 1990; Rudolf and Phipps 1974). Macdonald (1986) suggested collecting European hornbeam seeds in the fall, followed by extraction, stratification for 8

Table 4—*Carpinus,* hornbeam: stratification treatments for breaking embryo dormancy

Species	Warm period Temp (°C)	Warm period Days	Cold period Temp (°C)	Cold period Days	Percentage germination
C. betulus	20	28	3–5	90–112	NS
	20	14	5	210	65
	20	30	4	120	65
C. caroliniana	20–30	60	5	60	10
	—	—	4.5	126	58
C. orientalis	20	60	5	90–120	NS

Sources: Allen (1995), Blomme and Degeyter (1977), Bretzloff and Pellet (1979), Bugala (1993), Rudolf and Phipps (1974), Suszka and others (1996).
NS = not stated.

Table 5—*Carpinus,* hornbeam: germination test conditions and results with stratified seed

Species	Test conditions* Temp (°C) Day	Test conditions* Temp (°C) Night	Test conditions* Days	Germination rate %	Germination rate Days	% Germination Avg	% Germination Samples	Purity (%)	Soundness (%)
C. betulus	20	20	70	30	7	18–90	50	97	60
C. caroliniana	27	16	60	2	12	1–5	2	96	62

Source: Rudolf and Phipps (1974).
*Tests were made in sand or soil.

weeks at 18 to 21 °C and then for 8 to 12 weeks at 0.5 to 1 °C, and then spring-sowing. Seeds collected later should be partially dried, stratified, and sown the next fall or the following spring to avoid having seedbeds with germination spread out over 2 years (Rudolf and Phipps 1974). Seeds should be sown in well-prepared beds at a rate of 323 to 431/m^2 (30 to 40/ft^2) and covered with 0.6 to 1.3 cm ($^1/_8$ to $^1/_4$ in) of soil (Rudolf and Phipps 1974). Macdonald (1986) suggested sowing seeds at a rate of 250/m^2 (23/ft^2) for lining-out stock and 150 to 250/m^2 (14 to 23/ft^2) for rootstocks. Fall-sown beds should be mulched with burlap, pine straw, or other material until after the last frost in spring (Rudolf and Phipps 1974). The soil surface should be kept moist until after germination, and beds should shaded lightly for the first year (Rudolf and Phipps 1974). Davies (1987, 1988) demonstrated that growth of European hornbeam transplants was greatly increased by using a chemical for weed control and various synthetic sheet mulches. Black polythene sheets (125 m thick) gave the best results for controlling weeds and aiding in tree establishment (Davies 1988).

Cultivars of hornbeam may be grafted (side whip or basal whip) or budded onto seedlings of the same species (Hartmann and others 1990; Macdonald 1986; MacMillan-Browse 1974). Hornbeam can also be propagated by cuttings, but with variable success. Stem cuttings of European hornbeam 'Fastigiata' rooted when treated with 2% (20,000 ppm) indole-3-butyric acid (IBA); American hornbeam 'Pyramidalis' with 1 and 1.6% IBA; heartleaf hornbeam (var. *chinensis*) with 1.6 and 3% IBA–talc; and Japanese hornbeam with 3 g/liter (3,000 ppm) IBA–talc plus thiram (Cesarini 1971; Dirr 1990; Dirr and Heuser 1987; Obdrzalek 1987). After rooting, the cuttings require a dormancy period (Dirr 1990). Placing cuttings at a temperature of 0 °C during the winter months satisfies the dormancy requirements (Dirr 1990). Stock plant etiolation and stem banding have been shown to improve the rooting of hornbeam (Bassuk and others 1985; Maynard and Bassuk 1987, 1991, 1992, 1996). Chalupa (1990) reported the successful micropropagation of European hornbeam by using nodal segments and shoot tips as initial explants. Oriental hornbeam has been established in bonsai culture (Vrgoc 1994).

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