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Tsuga 'Traveler' and 'Crossroad'—The First Adelgid-resistant Interspecific Hemlock Hybrids

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Hemlocks [*Tsuga* (Endl.) Carrière] are foundational, climax coniferous evergreen trees in forested ecosystems and are also iconic in cultivated landscapes. In the United States, the eastern hemlock, *T. canadensis* (L.) Carr., is a well-known and economically significant species for forest and cultivated landscapes. However, this species, along with the Carolina hemlock, *T. caroliniana* Engelm., is highly susceptible to feeding damage by the introduced hemlock woolly adelgid (HWA), *Adelges tsugae* Annand (Hemiptera: Adelgidae). Although the insect can be partially controlled using a combination of cultural practices, insecticides, and biological control methods, a critical component of long-term control will likely be genetic host resistance (McCarty and Addesso 2019; Vose et al. 2013).

Scientists at the US National Arboretum initiated a breeding program in the 1990s to develop new hemlock hybrids with improved resistance to HWA and superior ornamental traits. Breeding strategies are focused on interspecific hybridizations to incorporate HWA resistance found in Asian *Tsuga* species [*T. chinensis* (Franch.) E. Pritz, *T. diversifolia* (Maxim.) Mast., and *T. sieboldii* Carr. (Hoover et al. 2009; Montgomery et al. 2009)]. These crosses have resulted in more than 100 confirmed interspecific hybrid plants (Bentz et al. 2002, 2007; Montgomery et al. 2009; Pooler et al. 2002). We have selected, evaluated, and released two of these hybrids, *T. chinensis* × *T. caroliniana* 'Traveler', and *T. caroliniana* × *T. chinensis* 'Crossroad', for their improved resistance to hemlock woolly adelgid and outstanding ornamental and growth characteristics. These are the first interspecific hybrid hemlocks to be introduced to the horticultural trade and represent new strategies for managing HWA in landscape settings.

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Origin and Development

'Traveler' originated from a controlled cross made at the National Arboretum in 1992 between *Tsuga chinensis* NA 12347 (female parent) and *T. caroliniana* (male parent) located at the former David Fairchild Estate, Bethesda, MD. The breeding objective was to incorporate the HWA resistance of *T. chinensis* into an attractive landscape tree that resembled the native eastern North American *Tsuga* species. Twelve seedlings of this cross were identified as hybrids and planted as part of a larger field trial for evaluation beginning in 2002. 'Traveler' was selected as one of the most resistant hybrids based on field and polyhouse artificial inoculations of clonal plant material (Montgomery et al. 2009). Clonal field trials were conducted in North Carolina, and plants were distributed for additional evaluation to sites in Connecticut, Kansas, Massachusetts, Maryland, Oregon, Pennsylvania, and Tennessee beginning in 2011. The original tree and asexual propagules were observed for 20 and 10 years, respectively, for landscape attributes and HWA resistance and showed consistent resistance to HWA in field and container inoculation trials.

Tsuga 'Crossroad' originated from a controlled cross made in 1998 between *T. caroliniana* (84-2069) (female parent) and *T. chinensis* (NA 12347 (male parent) at the Orland E. White Arboretum in Boyce, VA. Twenty-five seedlings of this cross were identified as hybrids and planted in the same large field trial mentioned above beginning in 2002. Along with 'Traveler', 'Crossroad' was one of several plants showing resistance to HWA in field and polyhouse inoculation trials (Montgomery et al. 2009), and was included in the clonal field trials in North Carolina. Propagules were distributed for evaluation to sites in Kentucky, Massachusetts, Maryland, Ohio, Oregon, Pennsylvania, and Tennessee beginning in 2015.

Description and Performance

Tsuga 'Traveler' (National Arboretum No. NA81144, Plant Introduction No. PI690762) has pendulous branches and a pyramidal growth habit, increased resistance to hemlock woolly adelgid, and a moderately slow growth rate. Mature plants were 9.0 m tall and 5.5 m wide in 2017, after 15 years of growth in Beltsville, MD, and 10 m tall and 7.3 m wide after 20 years of growth (Fig. 1A). Trunk diameter at breast height of the original tree was 28 cm at 15 years and 32 cm at 20 years. Clonal propagules grew to a height of 3.5 m in 6 years in Laurel Springs, NC. The main lateral branches ascend ~30 degrees above a horizontal axis with slightly pendulous branchlets (Fig. 1A). Needles are symmetrical, ~2 mm in diameter and 14 mm average length. The adaxial needle surface is green (RHS 137B) (Royal Horticultural Society and Flower Council of Holland 1966) with two white stomatal bands on the abaxial surface which become more prominent as needles mature. Large quantities of cones are produced most years in the original plant but were not observed on propagules in 6 years after planting in North Carolina. Cones are yellow-green (RHS 144A) and slightly glossy in September when unopened. Mature cones open in October in Maryland and are greyed-orange (RHS 164C-165D), ~3.5 cm long and 2.7 cm wide (Fig. 2). Open-pollinated seeds were collected in 2006, 2011, and 2019 from a total of 352 cones to test for viability; from those seeds, only two seedlings germinated, and both were weak and did not survive.

Tsuga 'Crossroad' (NA 81167; PI 693240) was selected for its symmetrical pyramidal growth habit with ascending branches, darker green color, and resistance to hemlock woolly adelgid. It has a moderate growth rate that has reached 11 m high and 5.7 m wide in 17 years of growth, and 12.3 m high and 8 m wide in 22 years in Beltsville, MD (Fig. 1B). Clonal propagules have grown to an average height of 4.5 m in 6 years in North Carolina. Needles are symmetrical, ~2 mm in diameter, 13 mm average length and with 2 stomatal bands on the abaxial surface. The adaxial needle surface of 'Crossroad' is green (RHS 137A) and the tree appears darker green than 'Traveler'. Relatively few cones are produced in late summer and are similar in size and color to those of 'Traveler'. Immature cones in September are yellow-green (RHS 146B) and measure 3 cm long and 0.9 cm wide. At seed shed, cones open to a more irregular shape, resembling the *T. caroliniana* parent, and measure ~3.1 cm long and 3.0 cm wide (Fig. 2). 'Crossroad' produces many fewer cones and seeds than 'Traveler', and

Fig. 1. Mature growth form of *Tsuga* 'Traveler' (**A**) and 'Crossroad' (**B**) grown in the field in Beltsville, MD.

Fig. 2. Mature and immature cones of *T. chinensis* × *T. caroliniana* 'Traveler' (**left**) and *T. caroliniana* × *T. chinensis* 'Crossroad' (**right**).

none resulted in viable seedlings based on germination tests conducted in 2019.

Both 'Traveler' and 'Crossroad' were developed for landscape applications, with the intention of selecting hemlocks with reduced need for pesticides to control HWA in a landscape setting. Our early breeding studies indicated that the resistant Asian species could be hybridized with *T. caroliniana*, but not with *T. canadensis* (Bentz et al. 2002; Pooler et al. 2002), a result that was supported later by genetic studies (Havill et al. 2008). In the landscape, 'Traveler' and 'Crossroad' are well suited for use as a specimen tree in a large yard, as an informal large screen, or as specimen trees in parks or commercial landscapes. Although they were specifically bred and selected for use in landscape settings, they may also prove useful in forest landscapes where *T. canadensis* cannot grow due to feeding pressure by the HWA. Further trials are needed in forest landscapes to confirm their adaptability, value, and impact on forest ecosystems. Introgression of *T. chinensis* into native stands *of T. canadensis* is unlikely, based on years of crossing data (Bentz et al. 2002; Pooler et al. 2002). However, it is possible that these hybrids could introgress with native *T. caroliniana* or could hybridize between themselves.

Culture

Both 'Traveler' and 'Crossroad' are hardy in US Department of Agriculture (USDA; 2012) Zones 6 and 7 and will perform well in moist, well-drained soil in full sun to partial shade. Like the parent species, they are tolerant of shade and so will perform in the landscape even as an understory tree. These cultivars can be clonally propagated by cuttings taken in December or January or in early summer, before the second flush of growth, using 3000 to 8000 ppm indole-3-butyric acid (IBA) or IBA combined with naphthaleneacetic acid under mist. Rooting occurs slowly over 8 to 24 weeks (Dirr and Heuser 1987; Harper and Weston 2016). All propagules have been observed to be identical to the original parent plant in all distinguishing characteristics. Rooted cuttings transplant well from containers into the landscape.

Availability

Genetic material of these cultivars has been deposited in the National Plant Germplasm System (USDA 2022), where it will be available for research purposes, including development and commercialization of new cultivars. The US National Arboretum does not have stock plants available for general distribution. 'Traveler' is protected by a US Plant Patent (US PP32,784 P2) and will be available through licensed wholesale and retail nurseries as early as 2024. Inquiries about licensing opportunities may be made to the corresponding author. 'Crossroad' is not patented; limited quantities can be requested through the National Plant Germplasm System (USDA 2022).

The Agricultural Research Service requests that appropriate recognition be made if this germplasm contributes to the development of a new breeding line or cultivar. Herbarium vouchers have been deposited in the US National Arboretum Herbarium. The names *Tsuga* 'Traveler' and 'Crossroad' will be registered with the International Registration Authority for Conifers in accordance with the International Code of Nomenclature for Cultivated Plants, 2016 (Brickell 2016).

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