ELMS AND DUTCH ELM DISEASE: A QUICK OVERVIEW

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In the 1930s Dutch elm disease (DED) was accidentally introduced from Europe into the United States. It had a devastating impact on American elm (*Ulmus americana*) and its relatives in urban and riparian environments. In the United States, the three-part pathosystem for DED is unique in that the affected elm species are North American, the pathogen originated in Asia, and the most common vector is a European beetle. Of the nearly 40 species of elms that span the globe from Asia to Europe to North America, European and North American species are the most DED susceptible. The disease outbreak was extremely costly and the scientific and regulatory reaction to the issue was interrupted by World War II, which allowed the disease to spread more rapidly (Campanella 2003).

DED initiated a burst of activity in the elm research community. Selection and breeding programs aimed at DED tolerance were initiated. The earliest began in the 1930s with collaboration between the Boyce Thompson Institute (Ithaca, NY) and Cornell University with the intentional infection of more than 20,000 elm seedlings with a goal of isolating resistant survivors (Sinclair et al. 1974). The results were disappointing as nearly 40 years later only 16 trees survived. All of the survivors had undesirable characteristics, and none of their tested offspring were DED tolerant. Breeding programs that began by crossing DED-tolerant American elms were initiated at the University of Wisconsin (UW) (Guries and Smalley 1990) and the U.S. Department of Agriculture National Arboretum (NA) (Townsend 2000). Elms that tested DED tolerant began to be released to the trade over the next several decades. These include the Liberty multiclone (UW), 'Valley Forge' and 'Jefferson' (NA), and 'New Harmony' (NA). After a long gap, other institutions have recently released more clones. Some of these clones are from sole survivors programs that resulted from exploration to find old American elms. Because such survivors often succumb to the disease later, and because the great majority of survivors that have been inoculated with the fungus show little or no disease tolerance, it has been argued that most sole survivors merely escaped infection (Becker 1996). Relative testing of the newer clones for DED tolerance against older DED-tolerant clones has yet to be reported. In addition to the NA and the UW, the Morton Arboretum (MA) in Illinois utilized Asian elm species in hybridization to generate useful urban elms that are DED resistant. Some of the more widely used examples are *Ulmus* 'New Horizon' (UW), 'Morton' (Accolade®), 'Morton Glossy' (Triumph®) (MA), and 'Frontier' (NA), although many more are commercially available. The National Elm Trial (Colorado State University, n.d.), now complete, will soon publish comprehensive findings on the performance of many hybrids in different regions as well as the performance of some American elm selections. Recently, it has been discovered that *U. americana*, once thought to be the only tetraploid species in the genus *Ulmus*, also exists in the diploid state in some U.S. populations (Whittemore and Olsen 2011). The significance of this discovery with regard to DED tolerance, breeding, and taxonomy is yet to be determined.

Much research has been done to try to understand what makes an elm tolerant of DED. The cycle of pathogenicity is well understood. Fungal spores (largely from the fungus *Ophiostoma novo-ulmi*) carried by beetles enter a wound generated by beetle activity. After spores germinate, the fungus begins to dissolve the cell walls and feeds on plant carbohydrates. Embolisms in the xylem occur and the tree reacts by making suberin and lignin and attempts to localize the pathogen by blocking vessels and tracheids with cell wall extensions called tyloses. If this does

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not occur rapidly (as in DED-susceptible clones) the xylem become ineffective and the tree cannot properly hydrate. Defense anatomy studies indicate a correlation between vessel size and susceptibility (Elgersma 1970, McNabb et al. 1970) but recently, other hydraulic parameters have been implicated (Martin et al. 2013). In addition, the time a tree breaks bud in the spring can affect its susceptibility (Ghelardini and Santini 2009). From a genetic standpoint, it is accepted that the inheritance of DED tolerance is complex and multigenic (Aoun et al. 2010, Townsend 2000). Elm defense chemistry is multifaceted and involves the biosynthesis of many compounds that act directly or in complex pathways (reviewed by Büchel et al. 2016). In summary, the elm defense system is a generalized one that aims at walling off the infected xylem to prevent the fungus from infecting new growth, and is controlled by many genes. Temporal and phenological aspects of *Ulmus* growth play a major role in susceptibility.

The first DED fungus to be found in the United States was the less aggressive *Ophiostoma ulmi* (Brasier 1991). By 1940, this species was largely replaced by the more aggressive *O. novo-ulmi* (Brasier 1991). A third species, *O. himal-ulmi*, has been identified as a naturally occurring endophyte on elms native to the Himalayas and the elms are largely asymptomatic. However, when European elms are purposely inoculated with it, it is pathogenic (Brasier and Mehrotra 1995). From a genetic standpoint, fungi are easier to analyze than trees or insects and their smaller genome, short life cycle, and ability to be grown in culture makes them easier targets for genetic dissection. DNA sequencing has been completed on the genome of *Ophiostoma novo-ulmi* (Forgetta et al. 2013) and *O. ulmi* (Khoshraftar et al. 2013). For more information on *Ophiostoma* see a recent review (Bernier et al. 2015).

With regard to the fungal vector, it appears that any insect that can place DED spores into a stem wound can accomplish inoculation, although in the eastern United States the bark beetles belonging to the genus *Scolytus* are the main vectors (Santini and Faccoli 2014). We now know that the DED fungus can attract more beetles by emitting certain volatiles (McLeod et al. 2005) and that the bark beetles can be infected with a certain mite that has sporotheceae, which can increase beetle spore load (Moser et al. 2010).

Studies and breeding of American elm have focused much more on DED and less on elm yellows (i.e., elm phloem necrosis), which is caused by a phytoplasma. This is a concern as elm yellows is lethal. There are many subgroups of this pathogen as indicated by genetic sequencing (Jović et al. 2011). There is no practical treatment or cure. Control would involve an aggressive pesticide program to kill the vectors, of which there are many leafhopper species. Another strategy to combat tree diseases is to generate genetically engineered trees. Genetic engineering for DED resistance in American elm has been accomplished with significant reduction in pathogen symptoms (Gartland et al. 2005), but concerns over regulatory issues and a lack of funding[2] have slowed down progress.

After reviewing the elm disease literature, many questions and issues remain and it is hoped these will be answered with future research. For breeders, an image database of mature examples of all elm species would be useful to ascertain their aesthetic value. In addition, trials that rank the performance of elms intended for landscape use have been done in fields, not cities. How would the relative performance of these elms be in urban settings where trees are exposed to road salts, drought, and restricted root areas? With about 35 elm species, most never utilized in breeding or genetic analysis, is there more opportunity for interspecific hybridization to produce new landscape elms? Will diploid American elms alter our understanding of American

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elm evolution, DED, or assist breeders in any way? What role does the DED fungus play in Asia where it is not a pathogen? American elms have played a key role in urban planning and in natural ecosystems. Arguments for funding research aimed at restoring this species are defensible.

A more comprehensive review (Marcotrigiano, in press), which also includes a list of elm germplasm available in the United States, has been accepted and will appear in the journal "Arboriculture and Urban Forestry."

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