Combined Proceedings IPPS 72:275-285. 2022.

Hazelnut (*Corylus*) Breeding at Rutgers University

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Keywords: eastern filbert blight, disease resistance, filbert, clonal propagation, seedlings, novel cultivars

Summary

The Rutgers University hazelnut (*Corylus* spp.) breeding program was started in 1996 by turfgrass breeder Dr. C. Reed Funk as one component of a project focused on temperate nut trees. In 2006, hazelnuts emerged as the target group of species due to a number of attributes that includes their small tree size, ease of making controlled crosses, relatively short generation time, and increasing demand for their kernels. In collaboration with Oregon State University, wide germplasm collection and evaluation efforts were undertaken to help identify trees with resistance to eastern filbert blight, the primary limiting factor of cultivation in the eastern U.S.A. This manuscript provides an overview of the Rutgers hazelnut breeding program starting from its inception and spanning over twenty years to the release of the first cultivars in 2020. It also describes collaborative efforts to develop "hybrid" hazelnuts adapted to colder regions.

INTRODUCTION

The hazelnut breeding program at Rutgers University was started by Dr. C. Reed Funk in 1996 as part of a larger project on temperate nut trees. Dr. Funk, who already had an esteemed 35-year career breeding cool season turfgrasses (Meyer and Funk, 1989), decided to shift his focus when nearing retirement age. He turned the turfgrass program over to a new plant breeder and used the resources and knowledge he had amassed at Rutgers to develop a new project on nut producing trees, inspired in part by J. Russell Smith's "Tree Crops: A Permanent Agriculture" (Smith, 1950). The author of this manuscript, Tom Molnar, began working with Dr. Funk at that time.

Following the same principles that proved very effective in the turfgrass breeding program (Meyer et al., 2017), an extensive germplasm collection effort was undertaken. Trees of many different species were obtained and planted across several Rutgers research farms. Species included black walnuts, Persian walnuts, heartnuts, hickories, pecans, chestnuts, gingko, almonds, pistachio, sweet-pitted apricots, and hazelnuts. The goal was to grow large, diverse populations of trees under low input conditions to help identify which species held the greatest potential for planting in the eastern U.S.A., a region where commercial tree nut production has historically been absent.

In addition to collecting plants already available in U.S.A. and Canada, the acquisition of nut tree germplasm from Central Asia and other parts of the former Soviet Union such as Russia, Ukraine, Moldova, and the Baltic countries was targeted. Seed collection in this region was made possible through the help of plant scientist Dr. David Zaurov who, before coming to Rutgers, was a professor of agronomy in Tashkent, Uzbekistan, and had ties to many institutions in the broader Soviet region. Annual overseas trips were made for nearly a decade, resulting in an extensive collection of seeds in addition to documentation and descriptions of germplasm holdings at former Soviet institutions previously unknown in the U.S literature. For examples, see Mirzaev et al. (2004), Abdushukur et al. (2009), Molnar et al. (2011), Zaurov et al. (2013 & 2015), and Capik et al. (2013). Planting continued for about 10 years and the Rutgers field trials eventually held more than 25,000 trees being evaluated for overall tree health, adaptation, nut quality, and nut yields. It is also important to note that Rutgers' ornamental tree breeder Dr. Elwin Orton and fruit tree breeder Dr. Joseph Goffreda were advisors on the early project, supporting Dr. Funk's transition from perennial grass to tree breeding. This interaction eventually connected Tom Molnar to the ornamental breeding program.

Abundant practical knowledge on growing and managing nut trees was gained over that first decade, and nearly all species showed significant breeding potential and opportunity for genetic improvement (Molnar et al., 2013). However, the expenses put forth to maintain the trees were very large, the field space required was considerable, and the long maturity times of most of the species reduced the ability to show progress in a reasonable time frame (*e.g.*, most pecans from germinated seed took over 10 years to first bloom). With the retirement of Dr. Funk in 2006, a decision was made to reduce the scope of the program to keep it sustainable in the long term. It was then decided to focus primarily on hazelnuts (**Fig. 1**).

Figure 1. Cluster of 'Somerset' European hazelnut (*Corylus avellana*) ready to fall from tree in September. (Photo by author)

Hazelnuts were selected because, in general, they appeared well adapted to the region and produced nuts abundantly with little inputs. Further, they were smaller trees (shrubs) that required less land resources to grow to maturity, which fit constraints at the university in New Jersey where land is a primary limiting factor. They also bloomed at a relatively young age (4-5 years from germination) and are easy to use in controlled crosses compared to many other tree crops. Lastly, hazelnuts have few pests or disease problems, aside from one major exception — eastern filbert blight (EFB) (**Fig. 2**), a serious stem-canker disease caused by the fungus *Anisogramma anomala* that is native to the eastern U.S.A.; however, this disease appeared to be an obstacle that could be managed through breeding. Based on these factors, it was decided that hazelnuts were the species where the greatest impact could be made in the shortest time and with the least resources. In 2008, hazelnuts became the primary focus of the nut tree breeding program at Rutgers with work discontinued on the other species.

Figure 2. Typical eastern filbert blight canker on European hazelnut exhibiting its "football shaped" stromata. The causal organism is *Anisogramma anomala*. (Photo by author)

Hazelnut Production Worldwide

The *Corylus* genus is recognized to hold at least 13 species native across a wide area of the northern hemisphere; all are monoecious, wind pollinated, and have edible nuts. Of the genus, the European hazelnut (*C. avellana*) is the main species grown commercially for nut production (Botta et al., 2019; Molnar, 2011). While wild *C. avellana* is commonly found throughout much of Europe into the Caucasus region to parts of western Asia, commercial cultivation exists primarily in locations near large bodies of water with mild, Mediterranean-like climates. Major producing countries include Turkey with about 65% of the world's crop followed by Italy (~12-15%), Azerbaijan (~5%), the United States (~5%), and the Republic of Georgia (~3%), with additional production in Chile, China, France, and a few other nations (Food and Agricultural Organization of the United, 2022). In the United States, 99% of hazelnut production occurs in the Willamette Valley of Oregon.

Hazelnut breeding is relatively recent with significant efforts occurring only since the 1960s at Oregon State University (OSU). Most other programs and efforts had been since discontinued except for as described later in this manuscript. Outside of the U.S.A. and Chile, most production orchards are comprised of region-specific, clonally propagated cultivars selected from local plant materials whose origins have been largely lost with antiquity (Mehlenbacher and Molnar, 2021). Studies show that cultivars and wild populations of *C. avellana* remain highly genetically diverse (Gökirmak et al., 2009; Muehlbauer et al. 2014; Oztolan-Erol et al., 2021), which supports opportunities for further genetic improvement (Molnar, 2011).

Eastern Filbert Blight

Attempts to grow European hazelnuts in the eastern United States have historically faltered because of EFB (Fuller, 1908; Molnar et al., 2005). *Anisogramma anomala,* its causal agent, is an ascomycete in the order Diaporthales. It is an obligate biotroph associated strictly with plants of the *Corylus* genus. Its natural host is *C. americana*, the wild American hazelnut, which can be found growing across a wide area of eastern North America east of the Rocky Mountains. Having evolved with the pathogen, *C. americana* is very tolerant of EFB, whereas the European hazelnut is highly susceptible; devastating stem cankers eventually kill most trees lacking genetic resistance (Revord et al., 2020; Capik and Molnar, 2012). The disease is considered the primary limiting factor of hazelnut production in the eastern U.S.A., and since its accidental introduction into Washington in the 1960s and subsequent spread into Oregon, is now the main challenge with growing hazelnuts across all of North America (Johnson and Pinkerton, 2002; Mehlenbacher and Molnar, 2021). Note that *A. anomala* remains confined to North America and strict quarantine rules are in place around the world to help prevent its spread (Jeger et al., 2018)

Breeding for resistance and/or tolerance to *A. anomala* is complicated by its 2-year life cycle that includes a 16–18-month latent period where it generates no outward symptoms (Johnson and Pinkerton, 2002). Further, there exists a considerable amount of genetic diversity among samples of the fungus collected across the U.S.A. and Canada (Muehlbauer et al., 2019). Diversity of the pathogen appears to be limited in the Pacific Northwest, however, where it is not native and spread has been attributed to a single point introduction (Davison and Davidson, 1973; Tobia et al., 2017). In addition, research has shown pathogenic variation is present; some cultivars and breeding selections deemed resistant to EFB in Oregon may succumb to disease in New Jersey and other regions (Molnar et al., 2010; Capik and Molnar, 2012). Adding extra complexity to the system, the pathogen has a giant genome for a fungus (>340 MB), which is composed of >85% repeat regions (Cia et al., 2013).

Collaboration With Oregon State University

Hazelnut breeding has been ongoing at Oregon State University (OSU), Corvallis, OR, since the late 1960s. The breeding program and its associated germplasm collection, when combined with that held at the U.S.D.A. National Clonal Germplasm Repository (also in Corvallis, OR), is considered the largest and most comprehensive in the world (Mehlenbacher and Molnar, 2021). The recent resurgence and expansion of the Oregon hazelnut industry can be credited to the EFB-resistant, high yielding cultivars released by OSU over the past decade.

Collaboration with OSU, specifically with plant breeder Dr. Shawn Mehlenbacher, has been ongoing since the very beginning of the Rutgers project and includes germplasm collection efforts as well as clonal and seedling evaluation. The stressful climate of central New Jersey with relatively cold winters and hot, humid summers positioned within the native range of the EFB pathogen makes for an ideal disease screening location. Dozens of clonal breeding selections and 1000s of seeds from controlled crosses made at OSU have been shared for evaluation. While the primary goal was the selections of improved EFB-resistant plants adapted to local New Jersey conditions, information learned on disease response at Rutgers has been regularly shared with OSU scientists to inform breeding efforts in the current U.SA.. commercial growing region.

Hazelnut Germplasm Collection Efforts

In addition to plants shared for evaluation from the OSU breeding program and germplasm collection, over 5,000 new seedlings from foreign germplasm collections were obtained and evaluated at Rutgers between the years 2002 to 2010. Seeds were collected from Russia, Ukraine, Poland, Moldova, Georgia, Latvia, Lithuania, Estonia, Italy, and Turkey. While most plants eventually died from EFB, about three percent were found to be resistant. Interestingly, these plants spanned nearly all collection locations representing a wide diversity of resistant germplasm (Muehlbauer et al., 2014). Today, when considering hazelnut germplasm at Rutgers and OSU, we have access to over 100 EFB-resistant accessions selected from more than 60 locations equating to a very significant pool of germplasm to support breeding (Molnar et al., 2018). The most promising have been used in controlled crosses with next generation selections now under evaluation. Multiple studies have also shown that most resistance seems to be controlled by only one or a few major genes, although quantitative resistance is also available; *R*-gene mapping projects are underway at OSU and Rutgers with current results summarized in Mehlenbacher and Molnar (2021).

New Cultivars from Rutgers University

In 2020, four cultivars were released from the Rutgers breeding program. They originated from some of the earliest breeding populations grown at Rutgers from controlled crosses made in 2000 and 2004 by Shawn Mehlenbacher at OSU. The new cultivars were selected based on their resistance to EFB as well as their kernel traits and yields in trials at Rutgers. A breeding goal was to release our highest yielding EFB-resistant plants that also produced nuts that would fit the existing world hazelnut market for blanched kernels (confectionary market). This includes kernel with a round shape (not oblong), size of 12-13 mm diameter, thin shells (kernel percent of over 45%), freedom from defects such as molds and split sutures, and very good blanching after roasting as shown in **Fig. 3**. Selection aspects are described in detail in Mehlenbacher and Molnar (2021).

Figure 3. Kernels of 'Monmouth' hazelnut showing round shape and excellent blanching after roasting.

Note that hazelnut cultivars are clonally propagated. In the past this was done by simple layering or stool bed layering, but today this has been largely replaced by micropropagation. However, success with hazelnuts is variable and somewhat genotype dependent with the European hazelnut tending to be easier to work with than the native American hazelnut and its hybrids (Bassil et al., 1992; Pincelli-Souza et al., 2022). The four cultivars described below have been established in axenic culture but vary in their phase of commercial production and availability to date.

'Somerset' (US Plant Patent # 32,494 P2) is the results of a cross of OSU 665.123 × 'Ratoli' (a cultivar with EFB resistance from Spain) made in 2000. It is a high yielding, compact tree with medium size, round kernels that have moderately good blanching. It has self-incompatibility alleles S_3 and S_{10} with S_3 expressed in the pollen. It has notably thin shells and tends to produce good crops even on young trees. Resistance to EFB originates from 'Ratoli' which carries a single *R*-gene that has been shown to provide resistance to *A. anomala* originating from multiple regions (Molnar et al., 2010). 'Somerset' became commercially available from propagation labs in the fall of 2022.

'Raritan' (US Plant Patent # 32,460 P2) is the result of a cross of OSU 539.031 × OSU 616.018 made in 2004. It is a high yielding, vigorous tree that produces medium size, round kernels that blanch well. It has self-incompatibility alleles S_3 and S_{22} with S_3 expressed in the pollen. 'Raritan' exhibits quantitative resistance to EFB, also known as horizontal resistance or tolerance. It is not immune to EFB but only develops very few cankers under high disease pressure, and those it does get are inconsequential and tend to not have fruiting stromata. 'Raritan' appears to be easy to propagate and became commercially available from propagation labs in 2021.

'Monmouth' (US Plant Patent # 32,462 P2) is the result of a cross of 'Sacajawea' × OSU 616.055. It is a high yielding tree that produces medium size, round kernels that blanch very well. It has self-incompatibility alleles S_1 and S_{12} with both expressed in the pollen due to co-dominance. It exhibits quantitative resistance to EFB similar to 'Raritan'. To date, 'Monmouth' is not widely available due to challenges in the multiplication stage in tissue culture.

'Hunterdon' (US Plant Patent # 32 461 P2) is a full sibling to 'Monmouth'. It is moderately high yielding tree that produces medium size, slightly oblong kernels that blanch very well and have a noticeably sweet flavor. It has self-incompatibility alleles S_1 and S_3 with S_3 expressed in the pollen. It exhibits quantitative resistance to EFB but tends to get more cankers than 'Raritan' and 'Monmouth'. To date, 'Hunterdon' is not widely available due to challenges in the multiplication stage in tissue culture.

Hybrid Hazelnuts

European hazelnuts are limited in their adapted range in the U.S. and Canada, mostly to USDA cold hardiness zones 6-8. In contrast, wild *C. americana* can be found growing in much colder regions that include Minnesota, North Dakota, and parts of Manitoba, Canada. The species also expresses resistance and high tolerance to EFB. Fortunately, it is possible to hybridize the two species and select interspecific hybrids that express the best traits of both species. An effort to do so has been ongoing, although intermittently, since the 1920s with *C. americana* 'Rush' hybrids developed in New York and by the USDA. Beyond this, significant progress, especially in adaptation to cold climates and EFB resistance, was made in the 1950s and 1960s by Carl Weschcke in Wisconsin (Weschcke, 1954) and later built upon by breeding at Badgersett research nursery in Canton, Minnesota (Rutter, 1987). Many 1000s of seedlings from Badgersett nursery have been planted across the Upper Midwest from which high-yielding selections have been made (Braun et al., 2019). Additional details on the history of hybrid hazelnut development in North America including other programs are described in Molnar (2011).

Building from the early beginnings of interspecific hybridization, renewed and bolstered efforts have been underway in the past 15 years to develop hybrid hazelnuts as a commercial crop for colder regions. This includes work by the Hybrid Hazelnut Consortium, established in 2008 and today comprised of OSU, Rutgers, the University of Nebraska, Lincoln, the University of Missouri, and the Arbor Day Foundation, as well as the Upper Midwest Hazelnut Development Initiative comprised of the University of Wisconsin, the University of Minnesota, the Savanna Institute, and several other private and public partners. Both groups are working on breeding and selection of improved, EFB-resistant, cold hardy hybrid hazelnuts with a focus on improved nut traits and yields. Regional evaluation trials have been established with advanced plant material now being planted for study across a wide area of the Midwest, Upper Midwest, and northeastern U.S.A.

An exciting early output from the Hybrid Hazelnut Consortium was the release of ‘OSU 541.147’ “The Beast” (US Plant Patent # 33,561) in 2020. It is the result of a cross of NY 616 (*C. americana* 'Rush' × *C. avellana* 'Barcelona') × *C. avellana* OSU 226.118 made at OSU in 1990 then evaluated at Rutgers since 2000 where it has performed very well. It is a vigorous, high yielding "hybrid" hazelnut tree with small nuts and adequate blanching after roasting. Most kernels are 9–11 mm in diameter and do have a high level of fiber compared to the Rutgers cultivars, but this is removed during roasting. It has S-alleles 8 and 23 with S8 expressed in the pollen, making it a compatible pollinizer for the other Rutgers cultivars. This cultivar is suggested for use primarily as a pollinizer in New Jersey, but growers may find that its high yields of nuts outweigh its small kernel size. Recent tests suggest it can be grown successfully in USDA Zone 5, making it a possible production cultivar in colder regions.

CONCLUSIONS

Although the breeding of multiple temperate nut species was unfortunately discontinued at Rutgers, the hazelnut program was continued and has thrived since its inception. Wide germplasm collection and evaluation in close collaboration with OSU and more recently the Hybrid Hazelnut Consortium and other partners has identified many sources of disease resistance and cold hardiness which support breeding efforts and significant progress. The new EFB-resistant cultivars released from Rutgers in 2020 for the Mid-Atlantic region are becoming available and the first orchards are being planted. Further, one hybrid hazelnut (‘OSU 541.147’) was also released that is showing promise for the Mid-Atlantic as well as slightly colder regions. The Rutgers, OSU, and Hybrid Hazelnut Consortium breeding pipelines hold many promising breeding selections that combine EFB-resistance and good quality kernels with better cold hardiness. These plants are now under test in multiple regions, and results are eagerly awaited by many growers interested in commercial hazelnut production around North America. The future for greatly expanded hazelnut production in the U.S.A. and Canada remains very bright!

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