The phenology and compatibility of Hazelnut (Corylus avellana) cultivars in Tennessee

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The Phenology and Compatibility of Hazelnut (*Corylus avellana*) cultivars in

**Tennessee**

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Departmental Honors Thesis

The University of Tennessee at Chattanooga

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Project Director

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Departmental Examiner

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Liaison, Departmental Honors Committee

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Chair, Departmental Honors Committee
Abstract

The Phenology and Compatibility of Hazelnut (*Corylus avellana*) cultivars in
Tennessee

The European hazelnut (*Corylus avellana* L.), is an important temperate zone nut
tree species for which there is an expanding demand worldwide. Historically, the Eastern
filbert blight disease (EFB), caused by the ascomycete fungus *Anisogramma anomala*,
has prevented commercial hazelnut growing in Tennessee. As part of a UTC hazelnut
cultivar trial, EFB resistant hazelnut cultivars and numbered selections from Oregon State
University and Burnt Ridge Nursery were planted in 2003 at Smith Farm in Ooltewah,
TN. Hazelnut trees are wind-pollinated, dichogamous, and self-incompatible, which
means they are not self-fertile, their male and female blossoms may open at different
times, and they must be cross pollinated. The low seed set observed in the UTC trial
may result from the local weather patterns and/or from a lack of adequate pollinizers. I
hypothesized that the pollen release and the pistil emergence (female flower receptivity)
are not occurring at the same time and therefore sufficient pollination is not occurring
amongst the cultivars in the trial. I also hypothesized that the pollinizers may not have the
correct *S*-alleles (genetic loci that regulate compatibility) for successful cross pollination.
I collected phenological data from thirteen cultivars in the orchard every week during the
normal pollination months of January, February, and March 2016. Furthermore, I
constructed a table of *S*-alleles for all varieties in the orchard and compiled records for
the weather for the orchard for the months of my study. The results of my one season of
observation do not support the hypotheses but do provide important baselines for further
investigation.
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**Introduction**

The European hazelnut (*Corylus avellana* L.), is an important temperate zone nut producing tree species for which there is an expanding demand for commercial use worldwide (Ghanbari, Me, Talaie, & Vezvaie, 2004). Turkey and Italy are the world’s largest producers of hazelnuts followed by the United States of America, Georgia, and Azerbaijan. (Food and Agriculture Organization of the United Nations, 2014). Hazelnuts are monoecious (has both male and female flowers on the same plant), dichogamous (stamens and pistils mature at different times), wind pollinated, and are normally not capable of self-fertilization. Phenology is the “study of periodic biological events in the plant and animal world that are influenced by the environment, especially temperature changes driven by weather and climate” (Črepinšek, Štampar, Kajfež-Bogataj, & Solar, 2012). Understanding the phenology of the hazelnut tree is essential to managing the crop and getting the best results. The phenology of the European hazelnut differs from most other monoecious trees because they bloom in midwinter. Since most of the trees are protandrous, meaning that the male stamen, or catkin, matures before the female pistil, the timing is key to the pollination process. Cross-pollination must occur in order for a good nut set in the hazelnuts. Pistillate anthesis, the flowering period of the plant during which the female flower parts are receptive to pollen, is temperature dependent and occurs during the winter months of December, January, and February (Olsen, Mehlenbacher, and Azarenko, 2000). If not pollinated, stigmas (the part of the pistil that receives the pollen) can remain receptive for 3 months (Thompson, 1979). Normally, the peak for hazelnut pollination in Oregon is in January. There are no known of reports in the literature for hazelnut pollination timing in Tennessee.
Two of the many factors that can determine nut set in hazelnut are: 1) Pollen-pistil compatibility must be present in the cultivars and 2) Climate and weather can accelerate pollen release before the pistil is exerted or delay the pistil from exerting.

Pollen-stigma incompatibility is important when considering pollinizers in orchard plantings (Ghanbari, Me, Talaie, & Vezvaie, 2004). Self-incompatibility is controlled by a gene locus (the S locus) with multiple alleles. There are two main types of self-incompatibility in flowering plants: gametophytic and sporophytic. Gametophytic self-incompatibility is when the haploid S genotype in the pollen is expressed and the pistil that contains the same S-allele causes the pollen tube growth to be stunted (Hampson, Azarenko, & Soeldner, 1993). Sexual compatibility in hazelnut is controlled by sporophytic self-incompatibility, in which the pollen’s S expression is controlled by the diploid parental genotype (Hampson et al., 1993). The S-alleles, or self-sterility genes, are codominant in the pistil and can be either dominant or codominant in the pollen (Mehlenbacher, 1997). This means that if an allele in the pollen is the same as the allele in the pistil, the cross is incompatible. For example, if a female flower with the $S_1S_2$ alleles is pollinated by another hazelnut tree whose pollen expresses the $S_2$ allele, the two trees are incompatible. However, if the $S_1S_2$ female flower crosses with $S_3$ pollen, it is compatible. Studies by Dr. Mehlenbacher and others at Oregon State University have revealed some 33 different alleles at the S locus in Corylus avellana L. in (Mehlenbacher, 1997, 2014). S-alleles can be used to determine compatibility amongst cultivars. In hazelnut, S-alleles have a dominance hierarchy, which means some alleles are more dominant than others, as shown in Figure 1.
Figure 1. Dominance hierarchy of $S$-alleles in hazelnut pollen. Alleles are dominant to alleles below them, and codominant with those at the same level. (Mehlenbacher, 1997, 2014).

In addition to $S$-allele incompatibility, the weather has a part to play with the dispersion of pollen and the exserting and receptivity of the pistillate flowers. The timing of the phases of hazelnut phenology strictly depends on the current temperature and previous year’s temperature (Wielgolaski, 1999). The production of hazelnuts is ideally limited to places with milder to warm summers, since hazelnut trees have poor heat tolerance; they are also limited to cooler winters, although many can tolerate extremely low temperatures, some as low as -15 °C (Črepinšek et al., 2012). Warmer air temperatures cause plant development to start earlier in the phenological cycle (Menzel et al., 2006). When temperatures are colder, the possibility of injury to the catkins is greater than to the female pistils (Molnar, Goffreda, & Funk, 2004). The hazelnut’s dates of flowering and leafing are dependent on chilling and heat requirements. According to Capik and Molnar, (2014), “Male (catkins, staminate) and female (pistillate) flowers have
different chilling requirements to break dormancy, with catkins typically having lower chilling requirements than the female flowers.” Hazelnuts typically require a very short period of heat requirement and can vary amongst different cultivars (Mehlenbacher 1991). Other variants such as wind speed and precipitation can also factor into pollination timing. The weather can surely alter flowering time of different genotypes of hazelnut, so different pollinizers need to be present to complement with the others.

Along with compatibility and weather, the density of pollinizers determines pollination efficiency. It is recommended around the world that pollinizer density range from 3% to 30%, and in Oregon, it is standard at 10% (Olsen et al, 2000). Recently, Oregon has recommended placing at least three different pollinizers that release pollen at different times during the ideal stage of pistil flower emergence so that pollination may occur in the orchard consistently (Olsen et al, 2000). Many experts suggest that hazelnut trees should be within 50 to 70 feet between them and their pollinizers.

**Table 1. List of hazelnut cultivars at Smith Farm in Ooltewah, TN.**

<table>
<thead>
<tr>
<th>Cultivars</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSU 553.09</td>
</tr>
<tr>
<td>OSU 659.044*</td>
</tr>
<tr>
<td>Gamma</td>
</tr>
<tr>
<td>Hall’s Giant</td>
</tr>
<tr>
<td>VR43-1</td>
</tr>
<tr>
<td>Willamette</td>
</tr>
<tr>
<td>Trazel*</td>
</tr>
<tr>
<td>Beaked Hazel*</td>
</tr>
<tr>
<td>Turkish Tree Hazel*</td>
</tr>
<tr>
<td>Corylus Americana*</td>
</tr>
</tbody>
</table>

*Denotes cultivar not used in the research.

Hazelnut trees were planted at the Smith Farm experimental orchard, in Ooltewah, TN, beginning in 2003. Plants of thirteen cultivars and selections were
obtained from Oregon State University (OSU) in Corvallis, Oregon and Burnt Ridge Nursery in Onalaska, Washington. An additional 6 cultivars were added to the plantings in 2007. Table 1 contains a list of all cultivars currently at the farm.

Originally, the hazelnut trees were planted to test resistance to Eastern Filbert Blight (EFB) in cultivars and EFB-resistant selections developed at OSU. The planting also included EFB-susceptible cultivars as controls. Overall, the trees planted were expected to range from fully susceptible to highly resistant. Eastern Filbert Blight, a major limiting factor to hazelnut production in the eastern US, is a parasitic fungal disease caused by the ascomycete fungus *Anisogramma anomala* that is indigenous to Northeast America, and which infects most species of *Corylus* (Plant Disease Diagnostic Clinic, 2015). The fungus normally infects the American hazelnut, *Corylus americana*, causing small cankers to form on the branches of the tree, but when introduced to the European Hazelnut, *Corylus avellana*, the fungus causes giant cankers and necrotic lesions, which eventually kill the tree (Plant Disease Diagnostic Clinic, 2015). Western Washington and the Willamette Valley of Oregon, which includes Corvallis, was far outside of the native range of *A. anomala*, so the production of EFB-susceptible European cultivars planted in the 1885 thrived there for many years in relative isolation. (Thompson, Lagerstedt, and Mehlenbacher, 1996; Hummer, 2000). The introduction of Eastern Filbert Blight in western Washington in October 1970, which moved down into the Willamette Valley, has led to the development of EFB resistance cultivars there. (Davison and Davidson, 1973; Mehlenbacher, 1994). Some of these EFB cultivars were worthy of trials in New Jersey (Molnar, Godreda, & Funk, 2004) and Tennessee.
Although showing much promise in the Tennessee trial, the cultivars have been plagued by poor fruit set and poor nut quality in some years.

The aim of this research was to evaluate pollen shed and pistillate flower emergence, and cultivar pollinator compatibility, in hazelnut cultivars and selections at Smith Farm in Ooltewah, TN for 3 months in order to better understand their response to the weather of the Southeastern region of the United States and to provide data on the phenology of the hazelnuts in the region. The data will help determine whether Tennessee is an adequate place to grow hazelnuts in an effort to one day commercialize hazelnut production.

**Materials and Methods**

For the present study, a total of 12 different cultivars and OSU selections were observed for 3 months, from January 1\(^{st}\), 2016 to April 1\(^{st}\), 2016 to determine the date of release of pollen and pistil emergence. All of the trees are grown on their own roots; they were propagated (cloned) by stool-bed layering. Most of the clones in this study have 2 or more trees representing them. The trees were planted at a 5 x 10 meter spacing (approximately 15 x 30 feet apart) in 16 rows of ten trees each. Seven of the 16 rows were planted in a completely randomized design (rows A-G); seven rows (H-N) were planted as two “commercial production blocks” consisting of two rows each of the cultivars ‘Lewis’ (rows I and J) and ‘Clark’ (rows L and M), flanked by rows of six different pollinator varieties (rows H, K, and N). Not included in the present study are one row (row O) of miscellaneous hybrids and two trees of *Corylus colurna*, and a partial row (row P) of *Corylus americana*. The cultivars that were studied are listed in Table 2.
with their source, planting date, and incompatibility alleles. The identification of most of the S alleles in the 13 cultivars come from the incompatibility research done by Dr. Shawn Mehlenbacher, at OSU (Olsen et al., 2000). The S incompatibility alleles for the cultivars are Clark (S_3 S_8), Hall’s Giant (S_5 S_15), Lewis (S_3 S_8), Tonda di Giffoni (S_2 S_23), VR4-31 (S_1, S_3), Willamette (S_1 S_5) (Olsen et al., 2000); Gamma (S_2 S_10), Delta (S_1 S_15), Epsilon (S_1 S_4), Zeta (S_1 S_1) (Mehlenbacher and Smith, 2004); OSU 553.09 (S_8 S_26), and Yamhill (S_8 S_26) (Mehlenbacher, 2009).

Table 2. Hazelnut cultivars used for tree phenology at Smith Farm in Ooltewah, TN during January 2016 to April 2016.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Source</th>
<th>Date Planted</th>
<th>Incompatibility S-alleles¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSU 553.09</td>
<td>OSU</td>
<td>25-Apr-03</td>
<td>S_8, S_26</td>
</tr>
<tr>
<td>Clark</td>
<td>Burnt Ridge</td>
<td>14-May-03</td>
<td>S_3, S_8</td>
</tr>
<tr>
<td>Delta*</td>
<td>Burnt Ridge</td>
<td>14-May-03</td>
<td>S_1, S_15</td>
</tr>
<tr>
<td>Epsilon*</td>
<td>Burnt Ridge</td>
<td>14-May-03</td>
<td>S_1, S_4</td>
</tr>
<tr>
<td>Gamma*</td>
<td>OSU</td>
<td>14-May-03</td>
<td>S_2, S_10</td>
</tr>
<tr>
<td>Hall's Giant*</td>
<td>Burnt Ridge</td>
<td>14-May-03</td>
<td>S_5, S_15</td>
</tr>
<tr>
<td>Lewis</td>
<td>Burnt Ridge</td>
<td>14-May-03</td>
<td>S_3, S_8</td>
</tr>
<tr>
<td>Tonda di Giffoni*</td>
<td>Burnt Ridge</td>
<td>14-May-03</td>
<td>S_2, S_23</td>
</tr>
<tr>
<td>VR43-1</td>
<td>Burnt Ridge</td>
<td>14-May-03</td>
<td>S_1, S_3</td>
</tr>
<tr>
<td>Willamette</td>
<td>Burnt Ridge</td>
<td>25-Apr-03</td>
<td>S_1, S_3</td>
</tr>
<tr>
<td>Yamhill</td>
<td>OSU</td>
<td>14-May-03</td>
<td>S_8, S_26</td>
</tr>
<tr>
<td>Zeta*</td>
<td>OSU</td>
<td>14-May-03</td>
<td>S_1, S_1</td>
</tr>
</tbody>
</table>

¹Dominant alleles in pollen for each cultivar are underlined.
*Pollinizer varieties included in ‘Clark and ‘Lewis’ production blocks

During the winter and early spring months of January, February, and March of 2016, the catkins and pistils of the hazelnut cultivars were observed once a week. Both the catkins (Figure 2) and the pistils (Figure 3) were rated on a one to three scale according to their stage in development.
CATKINS. Catkin stage times are not absolute, therefore the stages begin when 60% of the catkins exhibited the characteristics of the stage for each tree. The stage times were determined by observing 50 catkins randomly on each tree for each cultivar. Stage 1 (Figure 2A) for the catkins occurs when the catkin begins to elongate and stretch. Since each cultivar’s stamen grows at different rates, the beginning of this stage starts when the catkins are flaccid. Pollen release at this stage is minimal to none. Stage 2 (Figure 2B) occurs when the catkin is intermediately elongated and the individual stamens are beginning to pull apart from one another. There is partially pollen release during this time. Catkins begin Stage 3 (Figure 2C) when they are fully elongated, all the individual stamens are pulled apart, and pollen shed is at its peak. The stage ends once the catkin has shed mostly all of its pollen.

![Figure 2. Hazelnut Staminate (Catkin) development. From left to right: Stage 1 (A) (catkin elongating), Stage 2 (B) (intermediate elongation, partially pollen release), and Stage 3 (C) (fully elongated, pollen release peak). Pictures taken at Smith Farm in Ooltewah, TN.](image)

PISTILS. The pistillate flower development begins a little bit later than staminate catkins for most cultivars. Just as in catkin development, pistil stage times are not
absolute because all the flowers may not progress at the same rate on the tree. This being said, the stages begin when over 60% of the flowers exhibited that certain stage. Stage 1 (Figure 3A) begins when the floral buds are slightly open but the pistil flowers are not seen emerging. In the beginning of Stage 2, the styles can be seen exserting from the buds indicated by a red cluster (Figure 3B). The pistillate flowers are not fully separated at this point but can begin to be pollinated. Stage 3 (Figure 3C) occurs when the pistillate flowers have fully exserted and separated. However, the end of this stage, as stated previously, may last as long as 3 months if the stigma is not fertilized. For purpose of this research, the stage ends when the styles fall off the buds.

![Figure 3](image.png)

**Figure 3. Hazelnut Pistillate (Pistil) development. From left to right: Stage 1 (A) (pistillate flower not exserted), Stage 2 (B) (partially exserted), and Stage 3 (C) (pistils fully exserted). Pictures taken at Smith Farm in Ooltewah, TN.**

**WEATHER.** Since the phenology of the hazelnut depends so much on the weather and climate, temperature data was taken from the location of the Smith Farm in Ooltewah, TN from the Apple weather application on an iPhone. Precipitation was also collected during the study. The data collected was validated by data obtained from
Accuweather and US Climate Data (Accuweather & US Climate Data). The information was then used to determine to correlation between weather and the phenology of the hazelnut cultivars.

Results

COMPATABILITY. The compatibility of the twelve cultivars were compared with one another. OSU 553.09 and Yamhill cultivars (S8S26) both can pollinate and be pollinized by Delta, Epsilon, Gamma, Hall’s Giant, Tonda di Giffoni, VR4-31, Willamette, and Zeta. The Clark and Lewis cultivars (S3S8) both can pollinate and be pollinized by Delta, Epsilon, Gamma, Hall’s Giant, Tonda di Giffoni, and Zeta. The Delta cultivar (S1S15) can pollinate OSU 553.09, Clark, Gamma, Lewis, Tonda di Giffoni, and Yamhill. However, Delta can be pollinized by OSU 553.09, Clark, Gamma, Lewis, Tonda di Giffoni, VR43-1, Willamette, and Yamhill. The Epsilon cultivar (S1S4) can pollinate OSU 553.09, Clark, Gamma, Hall’s Giant, Lewis, Tonda di Giffoni, and Yamhill. However, Epsilon can be pollinized by OSU 553.09, Clark, Gamma, Hall’s Giant, Lewis, Tonda di Giffoni, VR43-1, Willamette, and Yamhill. The Gamma cultivar (S2S10) can pollinate OSU 553.09, Clark, Delta, Epsilon, Hall’s Giant, Lewis, Tonda di Giffoni, VR43-1, Willamette, Yamhill, and Zeta. However, Gamma can be pollinized by every cultivar except Tonda di Giffoni. The Hall’s Giant cultivar (S3S15) can pollinate and be pollinized by OSU 553.09, Clark, Epsilon, Gamma, Lewis, Tonda di Giffoni, VR4-31, Willamette, Yamhill, and Zeta. The Tonda di Giffoni cultivar (S2S23) can pollinate OSU 553.09, Clark, Delta, Epsilon, Hall’s Giant, Lewis, VR4-31, Willamette, Yamhill, and Zeta. Tonda di Giffoni can be pollinized by OSU 553.09, Clark, Delta, Epsilon, Gamma, Hall’s Giant, Lewis, VR4-31, Willamette, Yamhill, and Zeta. The
VR4-31 and Willamette cultivars ($S_3S_3$) can pollinate OSU 553.09, Delta, Epsilon, Gamma, Hall’s Giant, Tonda di Giffoni, Yamhill, and Zeta. However, they can only be pollinated by OSU 553.09, Gamma, Hall’s Giant, Tonda di Giffoni, and Yamhill. The Zeta cultivar ($S_1S_1$) can pollinate OSU 553.09, Clark, Gamma, Hall’s Giant, Lewis, Tonda di Giffoni, and Yamhill. However, Zeta can be pollinated by OSU 553.09, Clark, Gamma, Hall’s Giant, Lewis, Tonda di Giffoni, VR43-1, Willamette, and Yamhill. Table 3 shows the compatibility of the selected cultivars.
Table 3. Compatibility of selected cultivars at Smith Farm in Ooltewah, TN.

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>OSU 553.09 (S8S26)</th>
<th>Clark (S3S8)</th>
<th>Delta (S1S15)</th>
<th>Epsilon (S1S4)</th>
<th>Gamma (S2S10)</th>
<th>Hall's Giant (S1S15)</th>
<th>Lewis (S1S8)</th>
<th>Tonda di Giffoni (S2S23)</th>
<th>VR43-1 (S1S3)</th>
<th>Willamette (S1S5)</th>
<th>Yamhill (S8S26)</th>
<th>Zeta (S1S1)</th>
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<tbody>
<tr>
<td>OSU 553.09 (S8S26)</td>
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<td>C</td>
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<td>C</td>
<td>X</td>
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<td></td>
</tr>
</tbody>
</table>

C = indicates that the cross is compatible  
I = indicates an incompatible cross  
0 = indicates the cross is compatible in only one direction
**WEATHER.** Daily climate data was taken from Smith Farm and recorded in Figure 4. The average high temperature for January was 8.8 °C and the average low temperature was -1.4 °C; the maximum and minimum temperatures were 20 °C and -8.8 °C respectively. In February, the average high was 12.8 °C and the average low was 2.4 °C: the maximum was 24.4 °C and the minimum was -5.5 °C. March’s average high and low temperatures were 20.2 °C and 7.3 °C respectively. The maximum temperature for the month was 29.4 °C and the minimum temperature was -0.5 °C. An incremental rise in temperatures occurred over the three months, which was expected. However, from Figure 4 it can be seen there are three major peaks in temperature during January to March. The most significant peak occurred from January 27th to February 5th. The other peaks occurred from February 17th to March 1st and from March 6th – March 17th. Pistil emergence depends heavily on peaks in temperature.

Precipitation during the study fluctuated in accordance with normal levels. The total amounts of precipitation during the study in the months of January, February, and March were 98.3 mm, 186.9 mm, and 70.6 mm, respectively. Snowfall occurred on January 22nd and February 9th but the amount was insignificant: 5.1 mm and 7.9 mm, respectively. In Figure 4, four peaks of over 30 mm of precipitation can be seen with the highest peak being February 1st to February 4th. The highest peak coincidentally occurred during and after the most significant peak in temperature. Therefore, one might believe that these peaks in temperature and precipitation might have caused pistil emergence to begin and develop in the cultivars.
Figure 4: Graphical summary of the daily climate data at Smith Farm in Ooltewah, TN during the months of January, February, and March of 2016. (Data collected by Apple weather application. Data verified by Accuweather and US Climate Data.)
Figure 5. Graphical summary of hazelnut staminate (catkin) and pistillate (pistil) development in 13 cultivars from January 2016 to March 2016. The yellowish colored bars represent hazelnut catkin development. The colors correlate to the stages listed in the text (cream yellow is Stage 1, yellow is Stage 2, and yellow-orange is Stage 3). The pinkish colored bars represent hazelnut pistil development. The light pink is Stage 1, the pink is Stage 2, and magenta is Stage 3. The cultivars name is located between the catkin and pistil bars to which it correlates.
CATKIN DEVELOPMENT. In accordance with the beginning of Stage 1, the cultivars were placed in 3 groups: early group, mid group, and late group. The early group was comprised of the cultivars Tonda di Giffoni, Yamhill, Willamette, Lewis, OSU 553.09, Hall’s Giant, and Gamma. These cultivars began catkin elongation during January, the earliest being Tonda di Giffoni. Tonda di Giffoni began Stage 1 on January 2 and ended Stage 3 on March 30. The dates made this particular cultivar have the longest catkin development period out of the entire orchard. The last cultivar to begin elongation in this group was Gamma on January 24. The mid group of the cultivars were Clark, VR4-31, and Epsilon and started Stage 1 in early February. The mid group on average stopped pollen release around mid-March. Delta and Zeta were a part of the late group which did not reach Stage 1 until mid-February. Although Zeta ended Stage 3 on March 13, Delta did not cease pollen release until March 31 making it the last cultivar to release mostly all of its pollen. The dates of each staminate development stage of each select cultivar can be seen in Table 4. Figure 5 shows the graphical summary of the both the hazelnut staminate and pistillate development.
Table 4. Summary of catkin development in cultivars from Smith Farm in Ooltewah, TN in 2016.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Pollen Release End</th>
<th>Total Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSU 553.09</td>
<td>Jan 20</td>
<td>Feb 3</td>
<td>Feb 17</td>
<td>Mar 10</td>
<td>40 days</td>
</tr>
<tr>
<td>Clark</td>
<td>Feb 3</td>
<td>Feb 19</td>
<td>Feb 28</td>
<td>Mar 17</td>
<td>51 days</td>
</tr>
<tr>
<td>Delta</td>
<td>Feb 10</td>
<td>Feb 21</td>
<td>Mar 14</td>
<td>Mar 31</td>
<td>50 days</td>
</tr>
<tr>
<td>Epsilon</td>
<td>Feb 5</td>
<td>Feb 23</td>
<td>Mar 1</td>
<td>Mar 10</td>
<td>34 days</td>
</tr>
<tr>
<td>Gamma</td>
<td>Jan 24</td>
<td>Feb 13</td>
<td>Feb 28</td>
<td>Mar 19</td>
<td>55 days</td>
</tr>
<tr>
<td>Hall’s Giant</td>
<td>Jan 23</td>
<td>Feb 9</td>
<td>Feb 22</td>
<td>Mar 11</td>
<td>48 days</td>
</tr>
<tr>
<td>Lewis</td>
<td>Jan 15</td>
<td>Feb 1</td>
<td>Feb 21</td>
<td>Mar 15</td>
<td>60 days</td>
</tr>
<tr>
<td>Tonda di Giffoni</td>
<td>Jan 2</td>
<td>Feb 6</td>
<td>Mar 9</td>
<td>Mar 30</td>
<td>88 days</td>
</tr>
<tr>
<td>VR4-31</td>
<td>Feb 2</td>
<td>Feb 18</td>
<td>Mar 3</td>
<td>Mar 18</td>
<td>45 days</td>
</tr>
<tr>
<td>Willamette</td>
<td>Jan 12</td>
<td>Jan 28</td>
<td>Feb 18</td>
<td>Mar 18</td>
<td>66 days</td>
</tr>
<tr>
<td>Yamhill</td>
<td>Jan 5</td>
<td>Feb 2</td>
<td>Feb 23</td>
<td>Mar 26</td>
<td>81 days</td>
</tr>
<tr>
<td>Zeta</td>
<td>Feb 10</td>
<td>Feb 25</td>
<td>Mar 3</td>
<td>Mar 13</td>
<td>32 days</td>
</tr>
</tbody>
</table>

**PISTIL DEVELOPMENT.** Just as it was in staminate development, the cultivars were separated into early, mid, and late groups. The early group included Yamhill, Willamette, Tonda di Giffoni, and Lewis. Pistil development started primarily in mid to late January. Willamette exhibited the earliest time for Stage 1 in which it began on January 17th. Starting on the 30th of the month, Lewis was the last cultivar in this group to begin development, which was 9 days after the second to last cultivar in the group, Tonda di Giffoni. VR4-31, Delta, Epsilon, and Hall’s Giant make up the mid-group of pistil development. Three of the four cultivars in this group began pistil development on February 7th. The outlier was VR4-31, beginning on February 1st; this made VR4-31 one of the cultivars in which pistil development started slightly before catkin development. The remaining group of cultivars were OSU 553.09, Gamma, Zeta, and Clark. These cultivars began pistil development around the middle of February and
ended in early to mid-March. The full pistillate development dates of each selected cultivar can be seen in Table 5. Figure 5 shows the graphical summary of the both the hazelnut staminate and pistillate development.

Table 5. Summary of pistil development in cultivars from Smith Farm in Ooltewah, TN.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Pistil Exserting End</th>
<th>Total Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSU 553.09</td>
<td>Feb 10</td>
<td>Feb 19</td>
<td>Mar 1</td>
<td>Mar 13</td>
<td>32 days</td>
</tr>
<tr>
<td>Clark</td>
<td>Feb 13</td>
<td>Feb 22</td>
<td>Mar 1</td>
<td>Mar 7</td>
<td>23 days</td>
</tr>
<tr>
<td>Delta</td>
<td>Feb 7</td>
<td>Feb 17</td>
<td>Feb 27</td>
<td>Mar 16</td>
<td>38 days</td>
</tr>
<tr>
<td>Epsilon</td>
<td>Feb 7</td>
<td>Feb 21</td>
<td>Feb 27</td>
<td>Mar 12</td>
<td>34 days</td>
</tr>
<tr>
<td>Gamma</td>
<td>Feb 12</td>
<td>Feb 21</td>
<td>Feb 29</td>
<td>Mar 8</td>
<td>25 days</td>
</tr>
<tr>
<td>Hall’s Giant</td>
<td>Feb 7</td>
<td>Feb 19</td>
<td>Mar 14</td>
<td>Mar 29</td>
<td>51 days</td>
</tr>
<tr>
<td>Lewis</td>
<td>Jan 30</td>
<td>Feb 12</td>
<td>Feb 20</td>
<td>Mar 1</td>
<td>31 days</td>
</tr>
<tr>
<td>Tonda di Giffoni</td>
<td>Jan 21</td>
<td>Feb 23</td>
<td>Feb 28</td>
<td>Mar 8</td>
<td>47 days</td>
</tr>
<tr>
<td>VR4-31</td>
<td>Feb 1</td>
<td>Feb 20</td>
<td>Feb 29</td>
<td>Mar 6</td>
<td>31 days</td>
</tr>
<tr>
<td>Willamette</td>
<td>Jan 17</td>
<td>Feb 16</td>
<td>Mar 1</td>
<td>Mar 24</td>
<td>67 days</td>
</tr>
<tr>
<td>Yamhill</td>
<td>Jan 19</td>
<td>Jan 29</td>
<td>Feb 20</td>
<td>Mar 22</td>
<td>63 days</td>
</tr>
<tr>
<td>Zeta</td>
<td>Feb 9</td>
<td>Feb 23</td>
<td>Mar 1</td>
<td>Mar 7</td>
<td>27 days</td>
</tr>
</tbody>
</table>

**Discussions**

**COMPATIBILITY AND DEVELOPMENT.** According to Table 3, compatibility results show that for each cultivar there are at least 6 potential pollinizers. Since all of trees were 5 m (about 15 feet away) from the nearest tree and at maximum within 50 feet from a potential pollinizer, in accordance with pollen density standards at Oregon State University, adequate fertilization should be occurring regularly. However, in order to get the maximum fertilization, peak pollen release (staminate Stage 3) and full pistil emergence (pistillate Stage 3) should coincide with one another. The cultivars OSU 553.09, Clark, Epsilon, Lewis, and Zeta had problems correlating those stages with the
Hall’s Giant cultivar. Clark and Lewis ended the Stage 3 of catkin development on March 17th and March 15th respectively which was a few days after the full pistil emergence of Hall’s Giant on March 14th. This barely allowed the two stages to coincide and could be seen as insignificant. The catkin Stage 3 ended on March 10th for OSU 553.09 and Epsilon, and on March 13th for Zeta, days before Hall’s Giant’s full pistil emergence, meaning that there was no overlapping of the stages. Hall’s Giant’s pistil Stage 3 occurred so late that the peak pollen release for most of its compatible pollinizers did not adequately coincide with its full pistil receptivity. Tonda di Giffoni’s pollen release ended on March 30th making it the longest catkin development in the orchard. However, four of Tonda di Giffoni’s compatible cultivars’ full pistillate emergence did not occur during the full pollen release stage of the cultivars. The Delta cultivar was the most problematic pollinator in the orchard. The beginning of peak pollen release for the tree occurred on March 14th. Almost all of the cultivars that it is compatible with could not be pollinized during the full pistil emergence because of how late the ideal pollen release stage occurred.

The Hall’s Giant, VR4-31, Willamette, and Yamhill cultivars had no problems with correlation of the two ideal stages. All cultivars that they were compatible with could be pollinated at full pistil emergence with their peak pollen release according to the data. It is important to note that Yamhill’s Stage 3 pistil development lasted the largest number of days of any cultivar; the time allowed all compatible cultivars to release the maximum amount of pollen to pollinate the pistil when it was fully exserted. All cultivars could be pollinized by the Gamma cultivar at full pistil emergence while also pollinating Gamma at top pollen release, with the exception of Tonda di Giffoni. With Gamma’s
catkin Stage 3 beginning on February 28th and ending on March 19th, every cultivar’s full pistil emergence stage in the orchard was able to be pollinized at its maximum potential.

It was also seen in the study that several cultivars were not compatible in both directions. For example, VR43-1 and Willamette cultivars were able to pollinize Delta, Epsilon, and Zeta, yet could not be pollinated by those same cultivars. The same is true with the Gamma and Tonda di Giffoni cultivars.

**WEATHER.** The temperatures of the months of January, February, and March were particularly high in accordance with the average monthly highs and lows. The higher temperatures may have caused the pistils to exsert in the cultivars earlier than normal. The most significant peak in the temperature occurred between January 27th and February 2nd where the high was 24.4 °C and the low was 11.7 °C. The spike in temperature seemingly caused the pistil development of several trees to begin. According to Figure 5, directly after the spike, the cultivars OSU 553.09, Clark, Delta, Epsilon, Gamma, Hall’s Giant, VR4-31, and Zeta all began Stage 1 of pistillate development within 11 days. Furthermore, during the second peak in temperature (February 17th to March 1st), 10 of the 13 cultivars began stage 3 of pistillate development, the most significant stage in development, indicating that the rise in the temperature again may have caused full emergence of the flowers.

The amount of precipitation was lower than normal levels in January and March. The normal amounts of precipitation in January and March are 125 mm and 126 mm, respectively. In 2016, January had 26.7 mm less precipitation and March had 55.4 mm less precipitation than normal. Conversely, February exceeded its normal value, going from 123 mm (normal amount) to 186.9 mm. The increase in rainfall may have helped in
the development process of the pistillate but may have stunted the pollen release of the staminate. The two peaks of rainfall occurring from January 20th to January 22nd and February 2nd to February 3rd can be seen as helping pistillate development. They both occurred during the most significant peak in temperature which could have caused the initiation of pistil development. However, the peak of rainfall occurring from February 21st to February 24th may have caused the pollen on the stamen to clump together and stick to the catkin not allowing wind dispersion to have any effect. The two precipitation peaks on February 2nd to February 3rd and February 21st to February 24th nearly mirrored the first two peaks of the temperature According to Figure 4 and 5, precipitation, temperature, and catkin and pistil development correlate extremely well.

**Conclusions**

This study was intended to start the process of recording hazelnut phenology and compatibility at Smith Farm in Ooltewah, TN between 12 cultivars and numbered selections in response to observations of unexpectedly low fruit set by trees in the past in the experimental orchard. It was determined that catkin elongation and pollen release varied from cultivar to cultivar. Though air temperature did not play a major role in the development of the staminate catkins, precipitation surely did through the control of pollen release. However, the awakening from dormancy in the pistils, like previous research suggested, was mainly controlled by the increase of air temperature and precipitation. The results suggest that since air temperature and precipitation drastically increased around the end of January and beginning of February, many of the pistillate flowers began the process of emergence around that point as reflected in comparison of Figures 4 and 5. Also, a second increase in rainfall and air temperature during the end of
February and beginning of March caused pistils to fully exsert in many of the cultivars. The start of full pollen release correlated with the second peaks as well. Precipitation levels were lower than normal levels during the study. Normally, a decrease in precipitation has an effect on the development of the trees, but there is no evidence to say that the precipitation has been low before and will be low after this study. According to the data in Figure 5, most of the cultivars’ peak pollen release (Stage 3) occurred during full pistil emergence (Stage 3) which would not cause lack of pollination and low seed set.

Adequate S-allele diversity is present in the orchard to satisfy the compatibility requirements for cross pollination of all the cultivars. This means that there were enough compatible cultivars in order to pollinate each tree at the orchard. There were some incompatible combinations, such as Lewis and Clark, because the S-alleles matched each other. (It did not affect the pollination process as previously suspected for this orchard at Smith Farm.) In conclusion, although my experimental results do not strongly support my original hypotheses, interpretation of these results should be tempered by the fact that only one phenological cycle was represented in the study.

More phenological data, like the data collected for this thesis, would be necessary to draw any general conclusions. Data in the future could also include nut production, including total mass, kernel mass, good seeds, defective seeds, and blanks. Soil fertility could be measured from soil samples at the orchard to inspect how much elemental nutrients are in the soil. Insect damage from the Brown Marmorated Stink Bug, *Halyomorpha halys*, has appeared in the orchard within the past few years and is known to have disrupted hazelnut production in Oregon. Its impact here should also be included
in future data collection efforts. There should be a weather station installed at Smith Farm in order to get more accurate readings for temperature and precipitation along with other meteorological data such as humidity and wind speed.

The southeastern area of Tennessee seems like a viable region to grow hazelnut trees based on the results from 2016. Smith Farm, through the results of further studies, has the potential to expand into commercial production, but limitations such as Eastern Filbert Blight may affect the trees in the future. In summary, I hope this study combined with future studies at Smith Farm, will contribute to the success of commercial hazelnut production in Tennessee and the southeastern United States.

**References**


Wielgolaski, F. E. (1999). Starting dates and basic temperatures in phenological