Exploring New Technologies for Sustainable Viticulture in the Southeastern United States

by

Andrej W. Svyantek

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
December 10, 2016

Keywords: cropping potential, fruit quality, phenology, Pierce's disease resistance, plant physiology, *Vitis* spp.

Approved by

Elina Coneva, Chair, Professor of Horticulture
J. Raymond Kessler, Professor of Horticulture
James D. Spiers, Associate Professor of Horticulture

Abstract

In the southeastern United States, Pierce's Disease (PD) is the major limiting factor for production of *Vitis vinifera* L, European wine grapes. Recently bred, PD resistant 87.5% *V. vinifera* selections ('U0501-12', 'U0502-01', and 'U0502-10') from the UC Davis breeding program were planted at the Chilton Research Extension Center (CREC), Clanton, AL in 2010. A two-year study of the phenological development and viticultural characteristics was carried out during 2015 and 2016 in order to characterize *V. vinifera* in the high PD pressure environment of central Alabama. Results for dormant pruning weights indicate that all three selections grew vigorously based on estimated dormant pruning cane weight. 'U0501-12' produced the highest pruning weight (2.9 kg/vine), and the two remaining selections each exceeded 2.4 kg/vine in 2016. During 2015, all selections yielded between 8.7 kg/vine for 'U0501-12' and 10.9 kg/vine for 'U0502-10'. Through the 2016 season, 'U0502-10' was the most productive selection, yielding 13.4 kg/vine. 'U0502-10' also had the largest clusters, averaging between 467.4 g and 567.7 g. Based on the results of the first study, the vigor and productivity of *V. vinifera* grapevines in the Southeast hold great promise as a new technology for sustainable viticulture production in Alabama and the Southeast.

To complement the growing viticulture industry of Alabama and the Southeast, a rootstock study of commercially available scion and rootstock combinations was planted at the CREC in 2014. The second experiment consisted of the following treatments: 'Norton' own-rooted (OWR), 'Norton' grafted on 'Paulsen '1103' ('1103P'), grafted on 'Kober 5BB' ('5BB'), and on ‘Teleki 5C’ (‘5C’), as well as scion cultivar ‘Chardonel’ OWR and ‘Chardonel’ grafted on ‘1103P.’ Evaluations were conducted throughout the 2015 and 2016 growing seasons to determine the effect of rootstocks on phenological development, vegetative growth, and fruit quality characteristics of hybrid bunch grapes grown in central Alabama. Results indicate that during the first year of crop production, ‘Chardonel’ grafted on ‘1103P’ yielded 8.3 kg/vine. ‘Chardonel’ OWR and ‘Chardonel’ on ‘1103P’ were the best performing combinations in terms of cropping potential. Rootstock suckering was notable for ‘Chardonel’ grafted on ‘1103P’ where vines produced an average of 8 rootstock suckers per vine throughout the growing season, while no other combination exceed one rootstock sucker per vine throughout the year. Trunk cross-sectional-area (TCSA) indicated the treatments with the highest vigor at the end of the 2016 growing season were ‘Chardonel’ grafted on ‘1103P’ and ‘Chardonel’ OWR, while ‘Norton’ grafted on ‘5BB’ resulted in the lowest vigor of only 19.0 cm^2 TCSA. Continued research is needed with new *V. vinifera* selections, rootstocks, crop load, and canopy management techniques to enhance quality and sustainability of Alabama’s viticulture industry.

Acknowledgments

I am thankful for the guidance of my major professor, Dr. Elina Coneva, in directing me towards an understanding of the challenges associated with perennial fruit production in Alabama. Along with Dr. Coneva, my advisory committee, composed of Dr. Kessler and Dr. Spiers, has been critical in shaping my desire to conduct research and to follow experiments through to completion. Dr. Edgar Vinson was always available for assistance and advice during my time in Horticulture, for this I am ever in his debt. Additionally, station manager Mr. Jim Pitts at Chilton Research Extension Center ensured that I always had a team around me able to accomplish any task in the field; he and the CREC team made certain that my research vines were healthy and protected from the many pest pressures of the Southeast. Along with the great assistance I have received from the CREC team, I must also thank labmates, classmates, and friends Shu Chen, Michael Polozola, John Critser, Yihua Luo, Ashley Brantley, Sydney Holmes, and countless others without whom many of the tasks I faced would have felt much more daunting. I thank my mother and father who successfully reared me, fed me, and trained me to work stubbornly. Most of all, I am grateful for my wife, Zhuoyu, who has been patient, supportive, and helpful at each step in this process.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

‘1103P’	‘Paulsen 1103P’
‘5BB’	‘Kober 5BB’
‘5C’	‘Teleki 5C’
°B	Degrees Brix
°C	Degrees Celsius
g	Gram
h	hours
ha	Hectare
kg	Kilogram
L	Liters
m	meter
OWR	Own Rooted
PD	Pierce’s Disease
SSC	Soluble Solids Content
X.f.	*Xylella fastidiosa*

CHAPTER ONE

Literature Review

Grape Classification

A staple in world agricultural production, the grape is classified in the family Vitaceae, order Vitales (Keller, 2010). Plants from the family Vitaceae are distributed throughout temperate, tropical, and subtropical climate zones. Consisting of 1000 species in 17 genera, Vitaceae's most economically important plants belong to two genera, the muscadines, genus *Muscadinia* (2n = 40 somatic chromosomes), and the true grapes, genus *Vitis* (2n = 38 somatic chromosomes).

The genus *Vitis* is native to Europe, Asia, and North America; it grows predominantly within temperate and subtropical climates (Keller, 2010; Mullins et al., 1992). *Vitis vinifera* L. is the Eurasian species of most interest and economic importance, having the majority of cultivated grape varieties derived from it. With five main veined leaves, forked tendrils, and bark that sheds with maturity, plants from the genus *Vitis* produce nodes with woody diaphragms and soft secondary wood (Mullins et al., 1992). Production of adventitious roots allows cutting propagation, though only a few species were shown to root easily from dormant cuttings. Many wild species of *Vitis* are dioecious, however the cultivated *V. vinifera* have perfect flowers. All species of *Vitis* readily interbreed yielding fertile interspecific crosses, indicating a common ancestor for all *Vitis*; this and the vastly different agronomic characteristics between American and Eurasian species make *Vitis* attractive for breeding purposes (This et al., 2006; Terral et al., 2010; Keller, 2010). *Vitis* is composed of approximately 60 species worldwide, of which 40 species are native to Eurasia and 20 species are native to North America. With an expansive genome, containing somewhere in the range of 500 million base pairs forming 30,000 genes, *Vitis* is a diverse genus of plants with an extensive history of human cultivation (Terral et al., 2010; Keller, 2010; Myles et al., 2011).

American native grapes differ from Eurasian grapes in several prominent aspects: their buds are smaller, their shoots are thinner, their internodes are longer, and their leaves have a glossy surface (Keller, 2010). Several of the American *Vitis* have been important as wine and juice grapes; *V. labrusca* L. is a species with one of the largest economic impacts. ‘Concord’ and ‘Niagara’ are two of the most well-known cultivated varieties. Juice, wine, and jelly produced from *V. labrusca* cultivars are notable for their “foxy” flavor caused by methyl anthranilate, unique to the species. While being resistant to powdery mildew (*Uncinula necator* [Schwein.] Burrill) and crown gall (*Agrobacterium vitis* Ophel & Kerr), *V. labrusca* remains largely susceptible to grape phylloxera (*Daktulosphaira vitifoliae* Fitch), downey mildew (*Plasmopara viticola* [Berk. & Curt.] Berl. & De Toni), black rot (*Guignardia bidwellii* [Ellis] Viala & Ravaz), and Pierce’s disease (*Xylella fastidiosa* Wells et al.) (PD). The “summer grape”, *V. aestivalis* Michaux is a species difficult to propagate from cuttings. Cynthiana’ and ‘Norton’, two synonymous cultivars derived largely from *V. aestivalis*, are noted for their tolerance of cold, drought, and waterlogging and their resistance to powdery mildew, downey mildew, and PD (Reisch et al., 1993; Keller, 2010). Notable American species contributing less to the known cultivated varieties include *V. riparia* Michaux, *V. rupestris* Scheele, and *V. mustangensis* Buckley. The “riverbank grape”, *V. riparia,* is found along riverbanks; it is cold hardy and resistant to many fungal diseases, but susceptible to PD. The “rock grape”, *V. rupestris*, grows along creek beds. Ranging from Louisiana to Oklahoma, *V. mustangensis*, was utilized in the production of “mustang” wine during the 1800s. While *V. arizonica* Engelmann, *V. berlandierri* Planchon, and *V. candicans* Engelmann are not actively cultivated for quality fruit products, their tolerances and resistances are pertinent to grape breeding programs worldwide (Winkler, 1962; Keller, 2010).

Eurasian *Vitis*, made up of roughly 40 species, is prominent in Asia. From Eastern Asia, the most exploited species are *Vitis amurensis* Ruprecht and *Vitis coignetiae* Pulliat (Keller, 2010). The “Amur grape”, *V. amurensis*, is believed to be the most cold hardy *Vitis* species, growing natively in a range from Northeast China to Russian Siberia (Wan et al., 2008; Jing and Wang, 2013; Dong et al., 2013). Cultivars of *V. amurensis* have the earliest bud break of all species, up to 1 month earlier than *V. vinifera.* Some *V. amurensis* varieties in Northeast China bear hermaphroditic flowers (Keller, 2010) indicating a potentially long history of cultivation. Chinese and East Asian *Vitis* species grow in incredibly diverse climates, making their contribution to the gene pool immense (Wan et al., 2008). A Japanese native, *V. coignetiae,* is species that morphologically bears a great resemblance to the American species *V. labrusca* (Keller, 2010; Jing and Wang, 2013). *Vitis sylvestris* Gmelin, likely a subspecies of *V. vinifera*, is a dioecious wild vine termed “forest grape” found growing along damp woodlands on alluvial soils; it ranges from Central Asia to Europe (Keller, 2010). The most well-known of all the Eurasian species is *V. vinifera*, with hermaphroditic flowers, tolerance to alkalinity and drought, and a storied history of cultivation for table grapes and wine.

Biology and Exploitation of the Grapevine’s Roots, Shoots, and Fruit

Being a perennial deciduous woody vine, the grape is easily grown with structural support to bear the weight of each year’s shoots and fruits (Jackson, 2008). Due to the plant’s natural vining habits, early Roman cultivation of grapes utilized live poplar trees as vine support. These poplar trees have since been replaced with different training systems.

Each spring, regrowth initiates at the uppermost lateral bud on the lignified portion of a cane (Jackson, 2008). Cane ripening is described as radial growth of trunk and arms (Mullins et al., 1992). Each year the trunk thickens and canes and spurs experience renewed activity of the phloem and cambium. When warm weather arrives sap “bleeds” from canes and spurs that have been cut, this is followed by bud burst, return of function to the phloem, and production of new xylem and phloem tissue from the cambium. A primary shoot or cane is this year’s growth upon which fruit will be borne (Mullins et al., 1992; Jackson, 2008). Generally the primary buds are the only buds to activate, or “break”, in spring; secondary and tertiary buds remain dormant unless severe injury occurs to the primary bud (Mullins et al., 1992; Dry, 2000). Cordon training is utilized to create a manageable crop and to encourage fruit quality and quantity (Jackson, 2008). Cordon training may be done unilaterally, bilaterally, or quadrilaterally; however, bilateral horizontal cordons are the most common in commercial viticulture, often using spur pruning to maintain vines.

In viticultural systems vine training is essential for maintaining plant health and fruit quality (Jackson, 2008). Proper management of vines requires an understanding of the plant’s biology and regional needs. While training for *M. rotundifolia* and French American hybrids requires a relatively tall cordon system to allow for the new year’s fruit bearing shoots to hang down loosely, *V. vinifera* typically has a consistent vertical growth habit so cordons are maintained relatively low to the ground. Plant growth type and climate must be considered (Winkler, 1962). Training the vine serves to ease a grower’s work in mechanical maintenance tasks such as pruning, irrigating, and harvesting of vines while also promoting thorough ripening of fruits (Jackson, 2008). Shoots of *V. vinifera* possess oppositely occurring tendrils in a repeated pattern of tendril-tendril-no tendril (Mullins et al., 1992). Canopy health is encouraged when leaves undergo ample photosynthesis without shading other leaves, and proper airflow to avoid creating areas favorable to disease buildup (Jackson, 2008). Canopy size and structure is important to promote a good microclimate for plant health and berry maturation (Keller, 2010).

In nature, grapevines grown from seed form a tap root with secondary roots off the major axis (Mullins et al., 1992). However, in commercial viticulture, economically important cultivars are propagated vegetatively from a mother plant in a practice dating back to Roman times; these clonally propagated cuttings form a multi-classed root system (Mullins et al., 1992; Keller, 2010). The root system grows with thick branching roots in patterns dictated by the environmental and genetic interactions; *V. rupestris* has deeply penetrating roots adapted to its rocky natural environment in strong contrast to the root system of *V. riparia*, which develops at a wider and shallower angle (Jackson, 2008). Much of traditional viticulture developed in Mediterranean and semi-arid climates; in these climates, the success of the viticulture may partially be attributed to practices that overcome numerous soil stressors such as salinity, calcareousness, or inherent infertility. The root system of grapes consists of individual roots pushing through soil in search of nutrients, moisture, and air exchange, all the while sloughing cells off at the tips (Mullins et al., 1992). Arbuscular mycorrhizal fungi (AMF) associations are common among grape roots, with the fungi often providing tolerance to environmental stressors and nutrient availability (Jackson, 2008). The genera *Glomus, Acoulospora, Gigaspora,* and *Sclerocystis* are the main AMF aiding grapevines in uptake of phosphorous, zinc, copper, and other nutrients.

Balanced Pruning Theory

Vines may be trained to cordons, modified horizontal trunks with multiple fruiting spurs (Goldammer, 2013). Advantages to cordon training and spur pruning are that pruning requires less skill and time than other methods, mechanical pre-pruning is possible, and it creates a more uniform growing situation that may promote more uniform fruit maturation. However, spurs may die and the fruiting zone may change, rising gradually over time. A spur should be pruned to 2 to 4 buds, depending on the desired crop level (Winkler et al., 1962).

According to Winkler (1962), grapevine behavior and productivity may be manipulated using knowledge of pruning techniques. Pruning should be done when vines are dormant, after leaf drop and before bud break (Smart and Robinson, 1991). However, pruning early in the dormant season may lead to winter injury in areas with significant frost, so generally pruning is done just prior to bud break (Goldammer, 2013). Balanced pruning techniques seek to find and maintain a vine's balance between fruit yield and quality, and growth. Ideal cane growth should be approximately pencil size in diameter, strong, and not excessive in vigor. Weak canes indicate excessive retention of too many buds and should be taken into account next season. Similarly, canes of a diameter greater than thumb size indicate excessive vigor as a result of too few buds being kept.

Over-cropping and under-cropping may occur as a result of mismanaged vines (Smart and Robinson, 1991). Over-cropping occurs when too many buds are left at dormant pruning; this may lead to issues with berry maturation. Berries may struggle to reach acceptable sugar levels that can cause harvest delay and other complications (Goldammer, 2013). A delayed harvest under hot conditions may result in a flat tasting wine, lacking acidity. Along with berry issues, over-cropping may negatively impact vine growth the following season. Retaining too few buds will result in under-cropping. When too few buds are kept canes may be very vigorous, but fruit production is insufficient (Winkler, 1962).

There are many metrics to evaluate vine balance and three commonly used methods to achieve vine balance in terms of grape yield, fruit quality, and vine growth are known as average cane weight, pruning formula, and the Ravaz index (Goldammer, 2013). Average cane weight, a calculation of the mean pruned cane weight, is used as an indication of vigor. Pruning formula varies by variety, and consists of retaining a certain number of fruiting canes for the first pound of pruning weight followed by retaining an additional number of canes for each additional pound of pruning weight. For French American hybrids, crosses between North America *Vitis* spp. and the European *V. vinifera,* generally 10 to 20 canes are retained for the first pound of pruning weight, with an additional 10 canes retained for each pound after that. An established French American hybrid vine that had 4 pounds of pruning weight would warrant 20+10+10+10= 50 canes retained. Varieties of *V. vinifera* generally are in the range of 20 canes for the first pound and 20 canes for every pound pruned after that. The concept of the formula dictates that large vines should have more buds than smaller vines. In climates with severe risk of frost injury, additional buds should be retained as a buffer. The Ravaz index is an alternative ratio used to determine vine balance; it is a ratio of fruit yield to prune weight where the weight of fruit harvested per vine in the previous year is divided by the dormant pruning weight per vine in the current year. Ideal Ravaz index values vary by region and variety, but generally a yield to pruning weight number should be between 5 and 10 to limit vine vigor and encourage productivity. A number below 5 indicates more crop than what was harvested is possible and dictates an increase in bud number per vine. Conversely, a ratio of greater than 10 shows that crop thinning or bud reduction may be necessary. Measurements at pruning and harvest are important to anticipate the necessary steps to take in the following season to encourage or discourage growth as is deemed necessary (Smart and Robinson, 1991).

Berry Development and Ripeness

Berries undergo three main stages of development towards ripening (Jackson, 2008; Keller, 2010). Stage 1, lasting 6-9 weeks, starts with quick growth of the pericarp and seed; the seed undergoes morphogenesis, embryo formation, and endosperm growth (Keller, 2010). During stage 1, the berry is green, firm, highly acidic, low in sugars, and half of the maximal berry size and weight. The end of berry skin cell division marks the completion of stage 1. Lag phase, stage 2 has a duration of 1-6 weeks. The final stage of berry ripening, stage 3, lasts 5-10 weeks. Throughout veraison (onset of fruit ripening), berries ripen individually and maturation occurs over 7-10 days within each grape cluster. Veraison is marked by berry softening, an increase in sugar content, and a rapid shift from green berries to the mature berry color (Jackson, 2008).

Ripeness is evaluated by four major criteria: must (freshly pressed fruit juice) weight and sugar content, acid level, pH, and physiological characteristics (Jackson, 2008). Degrees Plato is the brewing standard for evaluating sugar content by must weight, but in America, New Zealand, and Australia, degrees Brix is the measurement used to assess sugar levels in grapes. One degree Brix is equivalent to 1 gram of sucrose (or sugar) per 100 grams of solution. Brix is often measured in the field using a light refractometer because, while sucrose and sugars in solution alter the specific gravity of a solution, they also alter its optical properties leading to a measurable distortion. Even though Brix is an approximation and not an exact measurement of sugar content, the refractometer and degree Brix is the tool of choice for growers conducting field analysis. Other similar systems are employed worldwide: degrees Oeschsle (º Oe) is used in Germany, degrees Klostenneuburger Mostwaage (º KMW) is used in Austria, and the Baume scale is used throughout France and most of Europe. Berry ripeness is also evaluated by examining total must pH and must titratable acidity (TA). TA is a measure of the major acids in a grape must consisting predominantly of tartaric and malic acid, but may also have citric and succinic acid in minor quantities. For TA of wine grapes, 0.60-0.80% is generally an acceptable range for red grapes and 0.65-0.85% is generally acceptable for white grapes.

Cultivar Definition and Development

Species and cultivar identifying characteristics are defined and discerned in the science of ampelography (Galet and Adams, 1979; Keller, 2010). Though the origins of ampelography may be dated back to the Renaissance, an early system for identification of rootstocks cultivated in France was developed by Pierre Galet, the father of modern ampelography (Galet, 1998; Keller, 2010). The system was further expanded to the classification of other vines. The basis of phenotypical classification is concerned with distinguishing among cultivars from the same species using a number of distinct traits to form a key for identification (Mullins et al., 1992). Ampelography assesses a plant’s shoot, leaf, inflorescence, berry, and seed characteristics (Galet and Adams, 1979; Galet, 1998). Indument, or hairiness, may be defined as wooly or pubescent (Galet and Adams, 1979). Wooly hairs may further be characterized as downy, felty, or cobwebby. Pubescent hairs are either bristly or velvety. Lack of hair is noted as glabrous. Leaves are analyzed for shape, size, and the depths and angles of lobes and sinuses. Leaf shape may be cordiform, cuneiform, truncate, orbicular, or reniform. Inflorescence is less extensively used, though it helps indicate plant sex. Berries and clusters are observed for size, shape, weight, density, texture, and flavor. Seeds are examined for shape and size, and weight percentage as compared to total berry weight.

Breeding of grape vines is conducted for many purposes including to increase tolerance and resistance to abiotic factors (salinity, drought, heat, cold, etc.), to increase resistance to biotic pathogens and pests, to increase yield, or to alter the physical and chemical make-up of fruits for improved quality (Alleweldt and Possingham, 1988; Chittaranjan, 2011). Traditional breeding takes advantage of the sexual stage of each vine; since most of the commercially cultivated varieties of *V. vinifera* are naturally hermaphroditic, an emasculation stage is necessary to prevent self-pollination (Chittaranjan, 2011). The vines need not flower simultaneously; pollen may be obtained from a donor, dried, and stored in a freezer for a limited time until use. Pollen is applied at the optimal stage to an emasculated hermaphroditic or naturally female flower. At the end of the season, clusters ripen and seeds mature before being collected. Seeds are maintained in storage until germination is desired, often following a stratification treatment.

Due to the grape’s slow maturing nature, certain tactics, such as removal of clusters uninvolved in the cross, may be employed to accelerate a breeding program (Srinivasan and Mullins, 1979; Mullins and Rajasekaran, 1981; Chaïb et al., 2010; Chittaranjan, 2011). Selection and assessment is very difficult at a seedling stage; marker assisted selection (MAS) and enzyme-linked immunosorbent assay (ELISA) tests may be utilized when specific genes or immune responses are being selected (Bautista et al., 2008; Chittaranjan, 2011). For physiological characteristics like berry color, flavor, or chemistry, plants must be grown beyond the seedling stage before evaluation is possible (Chittaranjan, 2011).

Focus of Selected Grape Breeding Programs

Grape breeding programs around the world are generally developed with the goal of creating new cultivars or rootstocks that are adapted to regional climates, resistant to pests or diseases, or have increased quality or novel traits. Following the introduction of North American pests and diseases (phylloxera and downy mildew) to Europe, French-American grape breeding programs such as those of Bertille Seyve and Victor Villard produced the cultivars ‘Seyval blanc’, ‘Villard blanc’, and ‘Villard noir’ using *V. vinifera* parents for quality traits and North American *Vitis* such as *V. rupestris* for crucial resistance traits (Reynolds, 2015). Interspecific crosses among North American *Vitis* were used in Austria, Italy, Hungary, and other European countries to produce rootstock cultivars capable of survival in phylloxera infested soils.

Similar interspecific crosses were made by U.S. breeding programs for the purpose of rootstock development for California and the Eastern U.S. (Cousins, 2005; Granett et al., 2001). The Geneva, NY based Cornell University breeding program produced several notable interspecific releases with a focus on cold-tolerance and enhanced fruit quality such as ‘Chardonel’ and ‘Traminette’ (Reynolds and Reisch, 2015). Recently, three cultivars ‘Corot noir’, ‘Noiret’, and ‘Valvin Muscat’ were released to support cold-climate grape growers (Reisch et al., 2006a; 2006b; 2006c).

Along with Cornell University, the University of Minnesota breeding program has produced unique wine cultivars with extreme cold hardiness including ‘Frontenac’, ‘La Crescent’, ‘Marquette’, and most recently, ‘Itasca’ (Hemstad and Breeder, 2015; McKee, 2016). While having an official breeding program at the University of Minnesota, the state of Minnesota has also produced numerous bunch grape cultivars through passionate hobbyist, Elmer Swenson, that have gained a reputation in the upper Midwest (Hemstad and Breeder, 20015). ‘Swenson

Red' and 'Edelweiss' were co-released with the University of Minnesota, and 'St. Pepin', 'St. Croix', 'Sabrevois', and 'La Crosse' are four of Swenson's many other cultivars planted today.

In the Southeastern U.S., breeding programs have focused on incorporating regional *Vitis* spp. germplasm to increase vine survivability amid PD and other fungal diseases prevalent in the Deep South. 'MidSouth', 'Miss Blue', and 'Miss Blanc' are three prime examples of Mississippi State University bred grapevines for the purpose of juice (Overcash et al., 1981; 1982; Stafne, 2016). They incorporated native species such as *V. aestivalis*, *V. labrusca*, *V. Champini*, *V. rupestris*, and *V. berlandieri* to gain critical resistances in these cultivars (Stafne, 2016). The breeding program of the University of Florida Research Center at Leesburg and Apopka, FL produced numerous grape cultivars targeted for production in under high PD pressure including 'Conquistador', 'Stover', 'Suwannee', 'Daytona', 'Blanc du Bois', 'Lake Emerald', and a muscadine containing *V. vinifera* parentage, 'Southern Home' (Halbrooks and Mortensen, 1989; Mortensen et al., 1994).

Pierce's Disease, the Major Limiting Factor for Southeastern V. vinifera Production

In the humid subtropical climate of the Southeast United States commercial cultivation of European wine grapes, *V. vinifera,* has largely been prevented by the presence of PD, a bacterial infection caused by *Xylella fastidiosa* (Wells et al.) (*X.f.*), a gram negative bacterium endemic to the region and limited to the plant's xylem (Hopkins and Purcell, 2002; Fritschi et al., 2007). The strains of *X.f.* known to cause PD of grapes are native to North and Central America, though the species also causes worldwide issues such as phony peach disease and plum leaf scorch in the genus *Prunus*, citrus variegated leaf chlorosis in the genus *Citrus*, and under the overarching term bacterial leaf scorch throughout kingdom Plantae (Hopkins and Purcell, 2002; Su et al., 2013). In regions of the Eastern United States with colder winter temperatures, PD infections are less severe; due to the exceptionally mild winters of the southeast, the bacterium is regionally more effective at overwintering and remains a consistent issue for growers (Feil and Purcell, 2001).

X.f. bacterial infection occurs through a variety of insect vectors, any sucking insect consuming xylem sap may serve as a vector for the bacterium (Almeida et al., 2005; Almeida, 2007). The bacterium is readily obtained when a sucking insect feeds upon a previously infected plant; the bacterium is subsequently transmitted to other plants on which the insect feeds (Almeida, 2007). For *X.f.*, all acknowledged vectors are found within the Order Hemiptera: suborder Auchenorrhyncha with the majority being placed in the family Cicadellideae. Insect vectors harboring *X.f.* bacterium are an efficient means of transferring PD between vines and other hosts (Hu, 2013). All known vectors are piercing sucking insects. Though spittlebugs of Cercopidae can transmit PD, the most notable vectors are known as sharpshooters, a specific kind of leaf hopper from the family Cicadellidae. Glassy-winged sharpshooters, *Homalodisca vitripennis* Germar, are widely acknowledged as a vector of PD, but other sharpshooters that may carry PD include the green sharpshooter (*Draculacephala minerva* Ball), the blue-green sharpshooter (*Graphocephala atropunctata* Signoret) and the red-headed sharpshooter (*Carneocephala fulgida* Nottingham) (Goldammer, 2013). Sharpshooters feed on young grape leaves by puncturing and sucking; they may leave a resulting “honeydew” of excrement. Leafhoppers are believed to only harbor bacterium for vine-to-vine infection during summer. Limiting vectors through reduction of sharpshooters may reduce overall bacterial load; eliminating alternative hosts, like blackberries and elderberries can limit bacterial breeding sites.

Following transmittance of the bacterium to a healthy plant, *X.f.* is believed to build a biofilm within the xylem by using xylem sap as a source of nutrients, thus clogging and preventing the conductance of water throughout the plant (Hopkins and Purcell, 2002; Stevenson et al., 2005). This blockage of vascular tissue leads to many of the typical leaf scorching symptoms associated with the disease. Recent work has indicated that PD pathogenesis may be related to LesA, a newly discovered secreted lipase/esterase enzyme similar to LipA of *Xanthamonas* sp., with hypersensitive responses occurring in grapevine leaves with accumulated LesA (Nascimento et al., 2016).

Being fatal to most *V. vinifera* dominant cultivars, spring symptoms of PD become apparent early in the season when new growth is late to bud out and new leaves are yellowed, malformed, or stunted. Inter-vein areas may be yellowed, appearing similar to Zn deficiency (Jackson, 2008). Though sometimes a vine may recover over the winter following sufficient curative chilling, when vines are infected early in the season the likelihood of their recovery greatly diminishes (Anas et al., 2008; Krivanek et al., 2006). As the growing season progresses into fall and summer, symptoms tend to become more drastic and noticeable (Stevenson et al., 2005). The issues caused by PD may be initially confused with Zn deficiency, salt burn, or various grape arm and trunk diseases. A yellow to red discoloration of the leaf may occur, typically starting at the leaf margin and progressing inwards, leaving behind dead scorched tissue, ultimately leading to the entire leaf blade browning and falling off with the petiole remaining in what is known as a leaf "matchstick," due to visible similarity. Infection is followed by plant death in 1-5 years depending on severity.

Grape Production Globally, Nationally, and Regionally

Bunch grapes (*Vitis* sp.) represent an economically and culturally important fruit crop with global production increasing from 63 million metric tons in 2003 to over 77 million tons in 2013, a 22% increase (FAOSTAT, 2013). In the U.S., production exceeded 8 million metric tons in 2015 (USDA-NASS, 2016). In the Southeastern U.S., bunch grape production is limited by PD (Hopkins and Purcell, 2002; Wells et al., 1987). As a result, Alabama's viticulture industry has developed around the cultivation of PD resistant hybrid bunch grapes and muscadine grapes. Increasing local interest in grape production is evident in the number of bearing acres in Alabama that grew from 215 in 2002 to 426 in 2012, a 98% increase (USDA-NASS, 2016).

Along with Alabama, other southeastern states of Florida, Georgia, and Tennessee have seen 113%, 69%, and 158% increases, respectively, in production acreage in the same period of time, though Louisiana and Mississippi reduced acreage by 30% and 51%, respectively. Increases have occurred in the number of vineyard operations with acres bearing in Alabama, Florida, Louisiana, Mississippi, and Tennessee. Only Georgia had a modest reduction in operation number with a 5% decrease from 2007 to 2012.

Survey based production data for Georgia from 2007 to 2015 indicated that total tonnage of grapes produced increased from 2,900 tons to 4,950 tons without a decline in price per ton (USDA-NASS, 2016). Price received per ton grew from $1,060 to $1,510 with an average price of $1,266 over the eight year span. An average of 2.9 tons were harvested per acre in the survey period; 2007 reported 2.4 tons per acre and 2015 reported 3.3 tons per acre.

Development of PD Resistant Grapevines

Developing PD resistant plants is critical for the cultivation of *V. vinifera* in the Southeast United States and for the longevity of the crop in regions, including California, where the glassy winged sharpshooter and causal bacteria were attributed with destruction of vineyards (Krivanek and Walker, 2005; Krivanek et al., 2006; Fritschi et al., 2007). *M. rotundifolia* has natural resistance or tolerance of PD, having evolved alongside the bacteria; however, as a result of its distant relationship with the European wine grape, *V. vinifera*, crosses have difficulty in producing fruitful and fertile progeny, though promise remains for rootstock breeding between the two genera (Ruel and Walker, 2006; Keller, 2010). Other native vines from North America have developed in conjunction with the bacteria, including *V. arizonica* and *V. candicans*; these vines readily hybridize within the genus *Vitis* (Keller, 2010; Chittaranjan, 2011). Resistance to PD is believed to be dominant in genetic expression (Krivanek et al., 2006). PdR1, the major gene involved with wild germplasm expressing resistance, is transferred from parent to progeny by Mendelian inheritance and is controlled by a dominant allele (Krivanek et al., 2006; Riaz et al., 2008). Polygenic inheritance of other genes involved in PD resistance is known, but less well understood (Krivanek et al., 2006). The current PdR1 genotype is derived from a *V. arizonica/ V. candicans* wild type plant growing in Monterrey, Mexico.

Hybrid Bunch Grape Cultivars 'Chardonel' and 'Norton'

'Chardonel' is a late ripening white wine variety developed by the New York State Experiment Station (Reisch et al., 1990). It has moderately vigorous vines that may be grown on its own roots in phylloxera infested soils. A moderately cold hardy variety (-10 to -15 °F), 'Chardonel' has perfect, self-fertile flowers and is the result of a 'Seyval' ×'Chardonnay' cross made in 1953. With a medium-late bloom time following a late bud break, cluster thinning is seldom necessary. 'Chardonel' is considered moderately susceptible to downy mildew, botrytis bunch rot, crown gall, black rot, and anthracnose. It is however highly susceptible to phomopsis cane and leaf spot, and powdery mildew, but not susceptible to injury by sulfur applications.

‘Norton’, also known as ‘Cynthiana,’ is composed of *V. aestivalis*; it bears blue-black colored berries on small to medium clusters (Reisch et al., 1993). Cluster thinning is generally not needed for these late blooming and vigorous vines that require approximately 125 days from bloom to fruit maturity at harvest (Ambers and Ambers, 2004). ‘Norton’ is considered slightly susceptible to downy mildew, black rot, botrytis bunch rot, crown gall, phomopsis cane and leaf spot, powdery mildew, and anthracnose (Rink, 2005). ‘Norton’ is sensitive to injury from sulfur application and is moderately cold hardy (-10 to -15 °F), but requires 180 frost free days for fruit maturation. ‘Norton’ does not tolerate extended periods of wet soil. For a north-south oriented, high-bilateral cordon trained ‘Cynthiana’ vineyard, Main and Morris (2004) found that yield, cluster number, pruning weight, and Ravaz index were not affected by leaf removal, but wines were darker in color when made from vines that had leaves removed. In a particularly hot year, with maximum temperatures of 35 °C or greater during veraison, removal of leaves resulted in reduced pH and malic acid content of grapes.

Previous research in our lab (Hu, 2013) suggests that ungrafted ‘Cynthiana’ grown at the Sand Mountain Research Extension Center in Crossville, AL had a relatively low dormant pruning weight at 0.8 kg/vine. In the experiment, ‘Cynthiana’ berries had the highest sugar content (19.8 %) out of the 11 cultivars studied and yielded 5.7 kg/vine; ‘Cynthiana’ was harvested in late August 2011 and mid-August 2012. In 2011, ‘Cynthiana’ and ‘Champanel’ were the last cultivars to begin shoot development, with no leaves emerged by early April. Phenological development was slower for ‘Cynthiana’ than ‘Champanel’ in terms of bloom. Veraison stage was not recorded for ‘Cynthiana’ until July 25 in 2011 and July 13 in 2012. ‘Lake

Emerald' was the only selection with a later onset of veraison in the study with berries not beginning veraison until August in 2011 and July 27, 2012.

Grape Rootstock Selections

Through the combination of scion and rootstock, viticulturists are armed with a unique tool to ensure crop production in grapes (Pongrácz, 1983). While scions are often selected for fruit quality or disease resistance, rootstocks are selected to overcome diverse environmental constraints including pests, diseases, and poor soil conditions (Galet, 1998). Alternatively, rootstocks may be selected to manipulate the timing of vine development, timing of fruit maturation, or vegetative growth characteristics of the scion (Pongrácz, 1983; Wolpert, 2005). Phenological development of grape roots begins following bud burst on shoots, rather than prior to shoot growth (Coombe and Dry, 1992). Rootstock also plays a role in the final grape must's yeast assimilable nitrogen (YAN) content that can alter fermentation, affecting not only the vine but the ultimate product of *V. vinifera* grapes, the wine (Stockert and Smart, 2008). The onset of phylloxera (*Phylloxera vitifoliae* Fitch) initiated the utilization of North American *Vitis* species for the breeding of rootstocks capable of high performance in the presence of the pest (Pongrácz, 1983; Rombough, 2002; Jackson, 2008). Rootstocks commonly used include '1103 Paulsen' ('1103P'), '5BB Kober' ('5BB'), and '5C Teleki' ('5C') (Pongrácz, 1983). Phylloxera resistant species include *V. berlandieri*, *V. riparia*, and *V. rupestris* (Pongrácz, 1983). Species resistant to root-knot nematodes (*Meloidogyne* spp.) include *V. champini*, *V. cinerea,* and *V. longii* (Mullins et al., 1992).

'1103P' is a rootstock bred from a *V. berlandieri* ×*rupestris* cross that imparts high to moderate vigor, with moderate tolerance of waterlogged soils (Pongrácz, 1983). '1103P' is tolerant of drought, salinity, and alkaline soils. In a rootstock and training trial of ‘Sunbelt’ grapevine, derived from open-pollinated ‘Concord’ Ravaz index was higher in ‘Sunbelt’ on its own roots and trained to Geneva Double Curtain (Morris et al., 2007). ‘Sunbelt’ grafted on ‘1103P’ had lower fruit pH when trained on a bilateral cordon and had greater pruning weight. Aerial root formation of ‘Petit Verdot’ grafted on ‘1103P’ was greater when compared to own-rooted plants following a major April freeze event in Oklahoma (Stafne, 2007). However, no difference was seen in any other cultivar when comparing own-rooted and ‘1103P’ grafted vines. In ‘Petit Verdot,’ 50% budbreak occurred 5 days earlier on its own roots than on ‘1103P’ grafted ones, and for own rooted vines, budbreak occurred 15 days prior to the major freeze events.

‘5BB’ is a rootstock resulting from a *V. berlandieri ×riparia* cross that gives scions moderate to high vigor (Galet, 1998, Pongrácz, 1983). This rootstock is not tolerant of waterlogged soils, drought, or excessive soil acidity. ‘5BB’ is tolerant of lime in soils, is moderately sensitive to salt, and has been observed to have reduced fruit set in highly fertile soils. In an Arkansas rootstock evaluation with ‘Chardonel’ scions, ‘5BB’ yielded the largest berry weight (Main et al., 2002). In the Fayetteville, AR planting, ‘5BB’ rootstocks had a 40% increase in yield, though ‘5BB’ also resulted in higher fruit pH and potassium concentrations that may be considered flaws in fruit quality for wine production. In a Missouri rootstock study using ‘Norton’ as the scion, ‘5BB’ yielded more fruit in larger clusters than own-rooted ‘Norton’ (Harris, 2013). Petiole phosphorous levels were below the acceptable range for both own-rooted and ‘5BB’, while calcium content was inadequate for ‘1103P’. ‘Chardonnay’ on ‘5BB’ produced fruit with the highest juice potassium and pH, while ‘1103P’ and ‘5C’ produced juice with the lowest potassium and pH level (Boselli et al., 1992). Schreiner (2003) found that ‘5BB’ imparted the highest vigor to scion ‘Pinot noir’ clone FPMS 2A, also noting increased levels of arbuscular mycorrhizal fungi colonization for ‘5BB’ grafted vines.

‘5C’ is a rootstock with *V. berlandieri ×riparia* lineage that enables moderate scion vigor (Pongrácz, 1983). ‘5C’ is not tolerant of waterlogged soils, drought, or acidic soils, but it is tolerant of lime in the soil and considered good for advancing vine maturity.

Goodman et al. (1993) reported ‘5C’ as crown gall susceptible and ‘5BB’ as resistant to crown gall. In a 6-year inoculation study, ‘5C’ had 13% survival rate (Süle and Burr, 1998). Roh et al. (2003) evaluated ‘1103P’, ‘5BB’, and ‘5C’ rootstocks and found them moderately susceptible to crown gall.

While flooding should be avoided by site selection, unpredictable conditions may bring periodic flooding in field conditions. Flooding intolerance can be confused with susceptibility to *Phytophthora cinnamomi* Rands, especially in field evaluations. Growth of flooded ‘Seyval Blanc’ vines grafted on ‘3309C’ rootstock continued at the same growth rate as unflooded vines over a 9-day period (Striegler et al., 1993). ‘St. George,’ ‘Riparia gloire,’ and ‘3309C’ rootstocks had greater flood tolerance than ‘5BB’, ‘Cynthiana’, and un-grafted ‘Seyval Blanc’. Root regeneration was not observed in ‘Cynthiana’ during the experiment. ‘1103P’ rootstock was highly susceptible to *P. cinnamomi* (Marais, 1979). In a comparison of 27 rootstocks, ‘1103P’ and ‘5C’ were drought tolerant, while ‘5BB’ was less tolerant of extended periods of drought (Carbonneau, 1985).

Soil acidity can negatively affect grapevines. Himelrick (1991) reported reduced root dry weigh and volume for ‘5BB’ rootstocks grown at low-soil pH (4.8). Soil pH below 5.5 can lead to Al and Mn toxicities that can adversely affect root growth and development (Foy et al., 1978; Taylor, 1988).

Pearson and Goheen (1988) found that PD resistance or tolerance is present in rootstocks with *V. aestivalis, V. berlandieri*, *V. champini*, or *V. rupestris* parentage. ‘Dog Ridge’ has very high PD resistance (Loomis, 1965; Pearson and Goheen, 1988). ‘Dog Ridge’ performed well under high PD pressure over an extended period of time in Florida (Mortensen 1972). ‘3309C’ vines had the most severe PD symptoms in a Tallahassee, FL study of un-grafted rootstocks grown under high PD pressure; vines were rated on a 0-5 scale where 0= no symptoms and 5= over 75% of leaves with marginal necrosis or vines were dead. ‘3309C’ vines received a score of 4.2 while ‘5BB’, ‘5C’, and ‘Ramsey’ scored 1.6, 1.9, and 1.0 respectively (Lu et al., 2003). ‘5BB’ had 70% survival after 3 years of cultivation in the field when compared to 90% survival of ‘5C’, 10% survival of ‘Freedom’, and 100% survival of ‘Ramsey’ rootstock.

Vine physiology and foliar characteristics may also be impacted by rootstock. ‘Riesling’ grapes grafted on ‘5BB’ had higher maximum photosynthesis rates compared to own-rooted vines (Düring, 1994). Similarly, ‘Muller Thurgau’ had higher photosynthesis rates when grafted on ‘5BB’ when compared to vines grafted on ‘5C’ (Candolfi-Vasconcelos et al., 1997). Chlorophyll content was highest in vines grafted on ‘5BB’ (Keller et al., 2001).

Vine growth, vigor, and yield may be affected by rootstock choice. Loomis (1952) found that rootstocks could improve yield, with yield increases noted for ‘Dog Ridge’ and other rootstocks. Yield increases were seen in all grafted vines by Hedberg (1980). For grafted ‘Gruner Veltliner,’ wood production was greater for ‘5BB’ and ‘5C’ when compared to own-rooted vines (Wunderer et al., 1999). ‘Gruner Veltliner’ grew more rapidly and fruit ripening occurred earlier when grafted on ‘1103P’ rootstock when compared to ‘5C’ rootstock (Fardossi et al., 1995). ‘Italia’ was higher yielding when grafted on ‘1103P’ rootstock when compared to own-rooted

(Ezzahouani and Larry, 1997). Own-rooted, unirrigated ‘Shiraz’ had greater yields than ‘Shiraz’ grafted on ‘1103P’ vines (McCarthy et al., 1997).

McCraw et al. (2005) found no differences among own-rooted ‘Chardonnay’ when compared to ‘Chardonnay’ grafted to ‘1103P’ or ‘5BB’ vines in fruit quality, harvest date, or yield characteristics. ‘Chardonel’ vines grafted to ‘5BB’ yielded 40% higher than own rooted vines (Main et al, 2002). ‘Chardonnay’ vines had reduced size and vigor when grafted on ‘5BB’ and ‘1103P’ (Ferroni and Scalabrelli, 1993). Reynold and Wardle (2001), comparing the rootstocks ‘5BB’, ‘5C’, and two other rootstocks with nine scions, found no impact of rootstock on yield per vine, clusters per vine, cluster weight, or berry weight.

In double guyot pruned ‘Sauvignon blanc’ vines with eight buds per cane and two yielding canes per vine grafted on ‘5BB’, ‘SO4’, ‘Börner’, and ‘41B/72’, vines grafted on ‘41B/72’ were the highest yielding (Pulko et al., 2012). However, ‘5BB’ fruit had higher total soluble solids content in both years and the highest average soluble solids over the two-year study.

Dodson (2014) found differences in yields and pruning weights of vines grafted to the rootstocks, ‘1103P’, ‘5BB’, and ‘5C’. In a Sacramento County CA ‘Chardonnay’ vineyard receiving 419 mm of annual rainfall, vines grafted on ‘1103P’ were highly productive, while ‘5BB’ and ‘5C’ grafted vines were moderately productive. Contrastingly, in a Sacramento County CA ‘Cabernet Sauvignon’ vineyard with 490 mm of rainfall, ‘5BB’ was the highest yielding rootstock followed by ‘5C’, with ‘1103P’ the lowest yielding vine. Yield was lowest for ‘5BB’ and ‘1103P’ grafted on ‘Zinfandel’ at an Amador County CA vineyard despite both rootstocks having the highest pruning weights when compared to ‘5BB’ grafted vines.

Use of native grasses as a cover crop resulted in the lowest pruning weights over a three-year study of ‘Merlot’ grafted on ‘5BB’ in a drip-irrigated Sacramento County CA vineyard (Ingels et al., 2001). Pruning weights were always significantly lower than those of the disked control without negatively affecting fruit yield, brix, or pH. Native grasses also resulted in the lowest petiole concentrations of nitrate-N and the lowest leaf blade total N.

Previous researchers have assessed the performance of *Vitis* grapevines in diverse climates, yet few successful performances with primarily *V. vinifera* have been had in the Southeastern U.S. Because of PD, little is understood about the developmental timing, vigor, fruit yield, or quality of *V. vinifera* vines grown in the humid subtropical environment of Alabama. While the diversity of Vitaceae has provided numerous native species adapted to the south’s various landscapes, few native grapevines offer the promise of quality found in European grapevines. Through discovering details about the developmental and vegetative traits of PD resistant *V. vinifera* in the southeast, there is anticipated to be uncovered a wide breadth of unique challenges beyond PD as are seen in any new viticultural climate.

Based upon the viticultural knowledge developed by prior studies, it was shown to be critical to understand as much as possible about the choice of grape cultivar, environmental constraints, the impact of local terroir, and local pest and pathogen populations to produce the highest quality crop through environmentally and economically conscious production practices. In the Southeastern U.S. where PD pressure has previously limited production solely to muscadines and hybrid bunch grapes, grape growers understand the significance of grape cultivar choice for its role in vine survivability and vineyard longevity.

Recently, 87.5% *V. vinifera* selections were obtained by two commercial vineyards in Alabama, representing the first southeastern commercial plantings of the UC-Davis bred PD resistant *V. vinifera* vines; this further necessitates the economic importance of viticultural research in Alabama and the southeast. To enable southeastern grape and wine producers to confidently grow *V. vinifera* vines, establishing an understanding of *V. vinifera* cropping performance and quality is critical to successful industry expansion.

Very little is known about the performance of hybrid bunch grapes in Alabama's climate. While Hu (2013) characterized the growth and development of numerous wine, juice, and table grapes at Alabama's Sand Mountain Research Extension Center, Crossville, AL and North Alabama Horticultural Research Center, Cullman, AL, no cultivar evaluated was composed of primarily *V. vinifera*; though successful, healthy, and productive cultivars were revealed for recommendation in Alabama's climate, no juxtaposition could be made to the potential of *V. vinifera* vine performance.

We conjecture that PD resistant *V. vinifera* vines will survive in central Alabama's climate, with mild winters and long growing seasons in spite of the endemic populations of *X.f.* and its vectors. Of the three UC-Davis developed PD resistant selections we hypothesize that all three selections will vary in their developmental timing, vegetative characteristics, and cropping traits. Additionally, we hypothesize that rootstock cultivar choice will have an effect on the economic feasibility of scion performance.

The main objective of our first study was to define the grape phenological development, vegetative growth, yield potential, vine vigor, and fruit quality for three PD resistant UC Davis developed *V. vinifera* selections grown in a high PD risk zone of Central Alabama. In a separate study we aimed to ascertain the effect of rootstock cultivars '1103P', '5BB', and '5C' on the growth and development of commercially available hybrid bunch grape cultivars 'Chardonel' and 'Norton' in the southeast. A 1999, an Alabama Cooperative Extension System publication suggested that ‘Tampa’, ‘Lake Emerald’, and ‘Dog Ridge’ as rootstock cultivar selections could be used across the state (Powell et al., 1999). However, the high vigor of ‘Dog Ridge’ may lead to a challenging management situation. With the potential opportunity for expansion into new PD resistant *V. vinifera* type bunch grapes requiring grafting for field production, rootstock evaluation for their effects on yield, vigor, and overall plant health becomes even more pertinent to enhancing sustainable pest management by proper rootstock cultivar selection. Along with the previously mentioned 87.5% *V. vinifera* selections, growers in Alabama and the southeast are also actively planting hybrid bunch grapes such as ‘Villard blanc’, ‘Blanc du Bois’, ‘Black Spanish’, and ‘Norton’ among others, cultivars which might benefit from rootstock use for vigor regulation, disease resistance, and increased plant longevity.

With the end goal of developing grower recommendations that promote sustainable and long-lived vineyards, it is our aim through this research to assess or determine viable PD resistant selections and rootstock cultivars suitable for providing our region with reliable viticultural growth, and grower success.

Literature Cited

Alleweldt, G. and J. Possingham. 1988. Progress in grapevine breeding. Theor. Appl. Genet. 75(5): 669–673.

Almeida, R.P. 2007. Glassy-winged sharpshooter transmission of *Xylella fastidiosa* to plants. Procedings Hawaiin Entomol. Soc. 39: 83–96.

Almeida, R.P.P., C. Wistrom, B.L. Hill, J. Hashim, and A.H. Purcell. 2005. Vector transmission of Xylella fastidiosa to dormant grape. Plant Dis. 89: 419–424.

Ambers, R.K. and C.P. Ambers. 2004. Dr. Daniel Norborne Norton and the origin of the Norton grape. Amer. Wine Soc. J. 36: 77–87.

Anas, O., U.J. Harrison,P.M. Brannen, and T.B. Sutton. 2008. The effect of warming winter temperatures on the severity of Pierce's disease in the Appalachian Mountains and Piedmont of the southeastern United States. Online. Plant Health Progress doi:10.1094/PHP-2008-0718-01-RS.

Bautista, J., G.S. Dangl, J. Yang, B. Reisch, and E. Stover. 2008. Use of genetic markers to assess pedigrees of grape cultivars and breeding program selections. Am. J. Enol. Viticult. 59: 248–254.

Boselli, M., M. Fregoni, A. Vercesi, and B. Volpe. 1992. Variation in mineral composition and effects on the growth and yield of Chardonnay grapes on various rootstocks. Agricoltura Ricerca. 14:138-139.

Candolfi-Vasconcelos, M.C., M. Kummer, M. Keller, P. Basler, and W. Koblet. 1997. Nitrogen response of *Vitis vinifera* Muller-Thurgau grafted on 6 different rootstocks: canopy characteristics and leaf gas exchange. Proc. of the Fourth Int. Symp. on Cool Climate Viticult. & Enol. Rochester, New York, USA. 3:32-36.

Chaïb, J., L. Torregrosa, D. Mackenzie, P. Corena, A. Bouquet, and M.R. Thomas. 2010. The grape microvine - a model system for rapid forward and reverse genetics of grapevines: grape microvines. Plant J. 62: 1083–1092.

Chittaranjan, K. (ed.). 2011. Genetics, Genomics, and Breeding of Grapes. Science Publishers. Boca Raton, FL.

Coombe, B.G. and P.R. Dry. 1992. Viticulture. Volume 2. Practices. Winetitles. Adelaide, Australia.

Cousins, P. 2005. Evolution, genetics, breeding: viticultural applications of the origin of our rootstocks. Proc. Grapevine Rootstocks: Current Use, Res., and Application. 1-7.

Dodson, J. 2014. Grapevine rootstock-scion interactions and influence on ripening periods and the initiation of senescence. Univ. California, Davis, PhD Diss.

Dong, C., Z. Zhang, J. Ren, Y. Qin, J. Huang, Y. Wang, B. Cai, B. Wang, and J. Tao. 2013. Stress-responsive gene ICE1 from *Vitis amurensis* increases cold tolerance in tobacco. Plant Physiol. Biochem. 71: 212–217.

Dry, P.R. 2000. Canopy management for fruitfulness. Aust. J. Grape Wine Res. 6: 109–115.

Düring, H. 1994. Photosynthesis of ungrafted and grafted grapevines: effects of rootstock genotype and plant age. Am. J. of Enol. and Viticult. 45:297-299.

Ezzahouani, A. and L.E. Larry. 1997. Effect of rootstock on grapevine water status, productivity and grape quality of cultivar Italia. *Bulletin de l'OIV.*

FAOSTAT. 2013. Food and Agriculture Organization of the United Nations. May 2016. <www.faostat3.fao.org/>.

Fardossi, A., W. Brandes, and C. Mayer. 1995. Influence of different rootstock cultivars on growth, leaf nutrient content and must quality of cultivar Gruner Veltliner. Mitteilungen Klosterneuburg, Rebe und Wein, Obstbau und Fruchteverwertung. 45:3-15.

Feil, H. and A.H. Purcell. 2001. Temperature-dependent growth and survival of *Xylella fastidiosa* in vitro and in potted grapevines. Plant Dis. 85: 1230–1234.

Ferroni, G. and G. Scalabrelli. 1993. Effect of rootstock on vegetative activity and yield in grapevine. Int. Symp. on Viticult. and Enol. 37-42.

Fey, C. D., R.L. Chancy, and M.C. White. 1978. The physiology of metal toxicity in plants. Annu. Rev. Plant Physiol. 29:511-566.

Fritschi, F.B., H. Lin, and M.A. Walker. 2007. *Xylella fastidiosa* population dynamics in grapevine genotypes differing in susceptibility to Pierce’s Disease. Am. J. Enol. Viticult. 58: 326–332.

Galet, P. 1998. Grape varieties and rootstock varieties. *Oenoplurimédia.* Chaintre, France.

Galet, P. and L.D. Adams. 1979. A practical ampelography: Grapevine identification. Cornell University Press, Ithaca, N.Y.

Goodman, R.N., R. Grimm, and M. Frank. 1993. The influence of grape rootstocks on the crown gall infection process and on tumor development. Amer. J. of Enol. and Viticult. 44:22-26.

Goldammer, T. 2013. Grape grower's handbook. A complete guide to viticulture for wine production. Apex Publishers. Centreville, Virginia.

Granett, J., M.A. Walker, L. Kocsis, and A.D. Omer. 2001. Biology and management of grape phylloxera. Annu. Rev. of Entomol. 46:387-412.

Halbrooks, M. C. and J.A. Mortensen. 1989. Origin and significance of Florida hybrid bunch grapes and rootstocks. HortScience 24:546-550.

Hedberg, P. 1980. Increased wine grape yields with rootstocks. Farmers' Newsletter 147: 22-24.

Hemstad, P. and G. Breeder. 2015. Grapevine breeding in the Midwest. p. 411-426. In: A.G. Reynolds (ed.). Grapevine breeding programs for the wine industry. Woodhead Publishing Ltd., Cambridge, UK.

Himelrick, D.G., 1991. Growth and nutritional responses of nine grape cultivars to low soil pH. HortScience. 26:269-271.

Hopkins, D.L. and A.H. Purcell. 2002. *Xylella fastidiosa*: cause of Pierce's disease of grapevine and other emergent diseases. Plant Dis. 86(10): 1056–1066.

Hu, Y. 2013. Feasibility of growing Pierce's disease tolerant American and French-American hybrid bunch grape cultivars and advanced grape selections in Alabama. Auburn Univ. Thesis.

Ingels, C.A., K.M. Scow, D.A. Whisson, and R.E. Drenovsky. 2005. Effects of cover crops on grapevines, yield, juice composition, soil microbial ecology, and gopher activity. Amer. J. of Enol. and Viticult. 56:19-29.

Jackson, R.S. 2008. Wine science: Principles and applications. Academic Press. Burlington, Massachusetts.

Jing, Z. and X. Wang. 2013. Genetic relationship between Chinese wild *Vitis* species and American and European Cultivars based on ISSR markers. Biochem. Syst. Ecol. 46: 120–126.

Keller, M., M. Kummer, and M.C. Vasconcelos. 2001. Soil nitrogen utilisation for growth and gas exchange by grapevines in response to nitrogen supply and rootstock. Austral. J. Grape and Wine Res. 7:2-11.

Keller, M. 2010. The Science of Grapevines: Anatomy and Physiology. Academic Press. Burlington, MA.

Krivanek, A.F., S. Riaz, and M.A. Walker. 2006. Identification and molecular mapping of PdR1, a primary resistance gene to Pierce's disease in *Vitis*. Theor. Appl. Genet. 112: 1125–1131.

Krivanek, A.F. and M.A. Walker. 2005. *Vitis* resistance to Pierce's Disease is characterized by differential *Xylella fastidiosa* populations in stems and leaves. Phytopathol. 95: 44–52.

Loomis, N.H., 1952. Effect of fourteen rootstocks on yield, vigor, and longevity of twelve varieties of grapes at Meridian, Mississippi. Proc. of the Amer. Soc. for Hort. Sci. 52:125-132.

Loomis, N.H. 1965. Further trials of grape rootstocks in Mississippi. Proc. Amer. Soc. Hort. Sci. 86:326-328.

Lu, J., Z. Ren, and P. Cousins. 2003. Field evaluation of grape rootstock response to natural infection by Pierce's disease. Pierce's Dis. Resistance Symp. Coronado, Calif. 19–22.

Main, G.L. and J.R. Morris. 2004. Leaf-removal effects on Cynthiana yield, juice composition, and wine composition. Amer. J. of Enol. and Viticult. 55:147-152.

Main, G., J. Morris, and K. Striegler. 2002. Rootstock effects on Chardonel productivity, fruit, and wine composition. Amer. J. of Enol. and Viticult. 53:37-40.

Marais, P.G. 1979. The situation regarding rootstocks resistant to *Phytophthora cinnamomi*. *Bulletin de l'OIV*. 52:357-376.

McCarthy, M.G., R.M. Cirami, and D.G. Furkaliev. 1997. Rootstock response of Shiraz (*Vitis* *vinifera*) grapevines to dry and drip-irrigated conditions. Austral. J. Grape and Wine Res. 3:95-98.

McCraw, B.D., W.G. McGlynn, and R.K. Striegler. 2005. Effect of rootstock on growth, yield and juice quality of *vinifera*, American and hybrid wine grapes in Oklahoma. Proc. Grapevine Rootstocks: Current Use, Res., and Application. 61-65.

McKee, L.J. 2016. Itasca joins list of cold-hardy grapes. Wines and Vines. 97:81.

Morris, J.R., G.L. Main, and R.K. Striegler. 2007. Rootstock and training system affect ‘Sunbelt' grape productivity and fruit composition. J. Amer. Pom. Soc. 61:71-77.

Mortensen, J.A. 1972. Dog Ridge, a superior grape rootstock for Florida. Proc. Fla. State Hort. Soc. 85:275-279.

Mortensen, J. A., J. W. Harris, D. L. Hopkins, and P. C. Andersen. 1994. ‘Southern Home': An interspecific hybrid grape with ornamental value. HortScience 29:1371-1372.

Mullins, M.G., A. Bouquet, and L.E. Williams. 1992. Biology of the grapevine. Cambridge University Press. Cambridge, United Kingdom.

Mullins, M.G. and K. Rajasekaran. 1981. Fruiting cuttings: revised method for producing test plants of grapevine cultivars. Am. J. Enol. Viticult. 32: 35–40.

Myles, S., A.R. Boyko, C.L. Owens, P.J. Brown, F. Grassi, M.K. Aradhya, B. Prins, A. Reynolds, J. M. Chia, D. Ware, C.D. Bustamante, and E.S. Buckler. 2011. Genetic structure and domestication history of the grape. Proc. Natl. Acad. Sci. 108: 3530–3535.

Nascimento R., H. Gouran, S. Chakraborty, H.W. Gillespie, H.O. Almeida-Souza, A. Tu, B.J.

Rao, P.A. Feldstein, G. Bruening, L.R. Goulart, A.M. Dandekar. 2016 The type II secreted lipase/esterase LesA is a key virulence factor required for *Xylella fastidiosa* pathogenesis in grapevines. Sci. Rep.18598. doi: 10.1038/srep18598.

Overcash, J.P., C.P. Hegwood, and B.J. Stojanovic. 1981. ‘MidSouth’ and ‘Miss Blue’ – two new bunch grape cultivars. Miss. Ag. & For. Expt. Sta. Res. Rep. 6(18).

Overcash, J.P., C.P. Hegwood, and B.J. Stojanovic. 1982. ‘Miss Blanc’ a new bunch grape cultivar. Miss. Ag. & For. Expt. Sta. Bull. No. 909

Pearson, R.C. and A.C. Goheen. 1988. Compendium of grape diseases. APS Press. Saint Paul, MN.

Powell, A., D. Himelrick, W. Dozier, and M.B. Musgrove. 1999. Fruit culture in Alabama: recommended rootstocks. ANR-53-G. 1-2.

Pulko B., S. Vrsic, and J. Valdhuber. 2012. Influence of various rootstocks on the yield and grape composition of Sauvignon Blanc. Czech J. Food Sci. 30:467-473.

Reisch, B.I., R.S. Luce, B. Bordelon, and T. Henick-Kling. 2006a ‘Corot noir’™ grape. N.Y. Food Life Sci. Bull. 159.

Reisch, B.I., R.S. Luce, B. Bordelon, and T. Henick-Kling. 2006b ‘Noiret’™ grape. N.Y. Food Life Sci. Bull. 160.

Reisch, B.I., R.S. Luce, B. Bordelon, and T. Henick-Kling. 2006c ‘Valvin Muscat’™ grape. N.Y. Food Life Sci. Bull. 161.

Reisch, B.I., R.N. Goodman, M. H. Martens, and N.F. Weeden. 1993. The relationship between Norton and Cynthiana, red wine cultivars derived from *Vitis aestivalis*. Am. J. Enol. Viticult. 44:441–444.

Reisch, B.I., R.M. Pool, W.B. Robinson, T. Henick-Kling, J.P. Watson, K.H. Kimball, M.H.

Martens, G.S. Howell, D.P. Miller, C.E. Edson, and J.R. Morris. 1990. ‘Chardonel’ grape. HortScience 25:1666–1667.

Reynolds, A.G. 2015. Grapevine breeding in the France- a historical perspective. p. 65-76. In: A.G. Reynolds (ed.). Grapevine breeding programs for the wine industry. Woodhead Publishing Ltd., Cambridge, UK.

Reynolds, A.G. and D.A. Wardle. 2001. Rootstocks impact vine performance and fruit composition of grapes in British Columbia. HortTechnology. 11:419-427.

Reynolds, A.G. and B.I. Reisch. 2015. Grapevine breeding in the Eastern U.S. p. 359-378. In: A.G. Reynolds (ed.). Grapevine breeding programs for the wine industry. Woodhead Publishing Ltd., Cambridge, UK.

Riaz, S., A.C. Tenscher, J. Rubin, R. Graziani, S.S. Pao, and M.A. Walker. 2008. Fine-scale genetic mapping of two Pierce’s disease resistance loci and a major segregation distortion region on chromosome 14 of grape. Theor. Appl. Genet. 117: 671–681.

Rink, J. 2005. The New Eastern Viticulture or Norton Revisited. Am. Wine Soc. J. 37:100–101.

Roh, J.H., H.K. Yun, K.S. Park, C.H. Lee, and S.B. Jeong. 2003. *In vivo* evaluation of resistance of grape varieties to crown gall disease. The Plant Pathol. J. 19:235-238.

Rombough, L. 2002. The grape grower: A guide to organic viticulture. Chelsea Green Publishing. White River Junction, VT.

Ruel, J.J. and A.M. Walker. 2006. Resistance to Pierce’s Disease in *Muscadinia rotundifolia* and other native grape species. Am. J. Enol. Viticult. 57: 158–165.

Schreiner, R.P. 2003. Mycorrhizal colonization of grapevine rootstocks under field conditions. Amer. J. of Enol. and Viticult. 54:143-149.

Smart, R. and M. Robinson. 1991. Sunlight into wine: A handbook for winegrape canopy management. Winetitles. Adelaide, Australia.

Srinivasan, C. and M.G. Mullins. 1979. Flowering in *Vitis*: conversion of tendrils into inflorescences and bunches of grapes. Planta 145: 187–192.

Stafne, E.T. 2007. Analysis of the April 2007 freeze event in Oklahoma. 10 March 2016. <http://www.grapes.okstate.edu/PDFs/2007/AnalysisoftheApril2007FreezeEventinOklahoma.pdf>.

Stafne, E. 2016. A history of bunch grapes research in Mississippi. J. of the Amer. Pom. Soc. 70: 158-164.

Stevenson, J.F., M.A. Matthews, and T.L. Rost. 2005. The developmental anatomy of Pierce’s disease symptoms in grapevines: green islands and matchsticks. Plant Dis. 89(6): 543–548.

Striegler, R.K., G.S. Howell, and J.A. Flore. 1993. Influence of rootstock on the response of Seyval grapevines to flooding stress. Amer. J. of Enol. and Viticult. 44:313-319.

Su, C. C., C.J. Chang, C. M. Chang, H. T. Shih, K. C. Tzeng, F. J. Jan, C. W. Kao, and W. L. Deng. 2013. Pierce’s disease of grapevines in Taiwan: Isolation, cultivation and pathogenicity of *Xylella fastidiosa*. J. Phytopathol. 161: 389–396.

Süle, S. and T.J. Burr. 1998. The effect of resistance of rootstocks to crown gall (*Agrobacterium spp.*) on the susceptibility of scions in grape vine cultivars. Plant Pathol. 47:84-88.

Taylor, G.J. 1988. Plant-soil interactions at low pH. Commun. Soil Sci. Plant Anal. 19:775-1413.

Terral, J. F., E. Tabard, L. Bouby, S. Ivorra, T. Pastor, I. Figueiral, S. Picq, J. B. Chevance, C. Jung, L. Fabre, C. Tardy, M. Compan, R. Bacilieri, T. Lacombe, and P. This. 010.

Evolution and history of grapevine (*Vitis vinifera*) under domestication: new morphometric perspectives to understand seed domestication syndrome and reveal origins of ancient European cultivars. Ann. Bot. 105: 443–455.

This, P., T. Lacombe, and M.R. Thomas. 2006. Historical origins and genetic diversity of wine grapes. Trends Genet. 22: 511–519.

USDA-NASS. 2016. Census of agricultural-state data. USDA Nat. Agr. Stat. Serv. May 2016. <https://www.nass. usda.gov/>.

Wan, Y., H. Schwaninger, D. Li, C.J. Simon, Y. Wang, and P. He. 2008. The eco-geographic distribution of wild grape germplasm in China. Vitis 47: 77–80.

Wells, J.M., B.C. Raju, H.Y. Hung, W.G. Weisburg, L. Mandelco-Paul, and D.J. Brenner. 1987. *Xylella fastidiosa* gen. nov., sp. nov: gram-negative, xylem- limited, fastidious plant bacteria related to *Xanthomonas* spp. Intl. J. Systematic and Evolutionary Microbiol.37: 136-143.

Winkler, A.J. 1962. General viticulture. University of California Press. Berkeley, CA.

Wolpert, J.A. 2005. Selection of rootstocks: Implications for quality. Proc. Grapevine Rootstocks: Current Use, Res., and Application. 25-33.

Wunderer, W., A. Fardossi. and J. Schmuckenschlager. 1999. Einfluss von drei verschiedenen Unterlagen und zwei Erziehungssystemen auf die Leistung der Rebsorte Grüner Veltliner in Klosterneuburg. Mitteilungen Klosterneuburg Rebe und Wein, Obstbau und Früchteverwertung. 49:57-64.

CHAPTER TWO

Evaluation of Phenological Development and Viticultural Characteristics of Selected Pierce's Disease Resistant *Vitis vinifera* L. Selections in Central Alabama

Abstract

Vitis vinifera L. grape production in the Southeastern United States is limited by the endemic bacterium, *Xylella fastidiosa,* causal agent of Pierce's Disease (PD). UC Davis bred *V. vinifera* selections: 'U0501-12', 'U0502-01', and 'U0502-10', represent a new technology that can help sustain the viticultural industry by reducing pesticide input and diversifying grape production. Experimental selections were grafted on PD resistant 'Dog Ridge' rootstock and planted at the Chilton Research and Extension Center in fall of 2010. In 2015-2016, studies were conducted to determine phenological development, viticultural performance, and survival of *V. vinifera* selections in the high PD pressure conditions of Alabama. Results for dormant pruning weights indicate that all three selections grew vigorously based on estimated dormant pruning cane weight. 'U0501-12' produced the highest pruning weight (2.9 kg/vine), and the two remaining selections each exceeded 2.4 kg/vine in 2016. During 2015, selections had a total yield between 8.7 kg/vine for 'U0501-12' and 10.9 kg/vine for 'U0502-10'. Through the 2016 season, 'U0502-10' was the most productive selection, yielding 13.4 kg/vine. 'U0502-10' also had the largest clusters, averaging between 467.4 g and 567.7 g. Soluble solids content for selection 'U0501-12' was highest among all selections in both years. None of the experimental vines tested under Alabama's high PD pressure have exhibited PD symptoms, and there have been no vine losses resulting from other pathogens. While the results for vine growth,

performance, and quality are very promising for the future of *V. vinifera* in the Southeast, further research is needed to refine concepts of vine vigor and yield balance to enable sustainable viticulture in the Southeastern U.S.

Introduction

A staple in world agricultural production, the grape is classified in the family Vitaceae, order Vitales (Keller, 2010). Plants from the family Vitaceae are distributed throughout temperate, tropical, and subtropical climate zones. Consisting of 1000 species in 17 genera, Vitaceae's most economically important plants belong to two genera, the muscadines, genus *Muscadinia* (2n = 40 somatic chromosomes), and the true grapes, genus *Vitis* (2n = 38 somatic chromosomes).

The genus *Vitis* is native to Europe, Asia, and North America; it grows predominantly within temperate and subtropical climates (Mullins et al., 1992; Keller, 2010). *Vitis vinifera* L. is the Eurasian species of most interest and economic importance, having the majority of cultivated grape varieties derived from it. With five main veined, hairy leaves, forked tendrils, and bark that sheds with maturity, plants from the genus *Vitis* produce nodes with diaphragms and soft secondary wood (Mullins et al., 1992). Production of adventitious roots allows cutting propagation, though only a few species were shown to root easily from dormant cuttings. Many wild species of *Vitis* bear dioecious flowers, however the cultivated *V. vinifera* have perfect flowers. All species of *Vitis* readily interbreed yielding fertile interspecific crosses, indicating a common ancestor for all *Vitis*; this and the vastly different agronomic characteristics between American and Eurasian species make *Vitis* attractive for breeding purposes (This et al., 2006; Terral et al., 2010; Keller, 2010). *Vitis* is composed of approximately 60 species worldwide, of which 40 species are native to Eurasia and 20 species are native to North America. With an expansive genome, containing somewhere in the range of 500 million base pairs forming 30,000 genes, *Vitis* is a diverse genus of plants with an extensive history of human cultivation (Terral et al., 2010; Keller, 2010; Myles et al., 2011).

Being a perennial deciduous woody vine, the grape is easily grown with structural support to bear the weight of each year's shoots and fruits (Jackson, 2008). Due to the plant's natural vining habits, early Roman cultivation of grapes utilized live poplar trees as vine support. These poplar trees have since been replaced with different training systems.

Each spring, regrowth initiates at the uppermost lateral bud on the lignified portion of a cane (Jackson, 2008). Cane ripening is described as radial growth of the trunk and arms (Mullins et al., 1992). Each year the trunk thickens and arms of spurs or rods experience renewed activity of the phloem and cambium. When warm weather arrives sap "bleeds" from canes and spurs that have been cut, this is followed by bud burst, return of function to the phloem, and production of new xylem and phloem tissue from the cambium. Fruit is borne on the current season's growth, a primary shoot or cane (Mullins et al., 1992; Jackson, 2008). Generally, the primary buds are the only buds to activate, or "break", in spring; secondary and tertiary buds remain dormant unless severe injury occurs to the primary bud (Mullins et al., 1992; Dry, 2000). Cordon training is utilized to create a manageable crop and to encourage fruit quality and quantity (Jackson, 2008). Cordon training may be done unilaterally, bilaterally, or quadrilaterally; however, bilateral horizontal cordons are the most common in commercial viticulture, often using spur pruning to maintain vines.

According to Winkler (1962), grapevine behavior and productivity may be manipulated using knowledge of pruning techniques. Pruning decreases a vine's ability to grow, instead concentrating an individual plant’s efforts into the remaining growth; heavy crops lead to low vine vigor and vice versa (Goldammer, 2013). Vine capacity is a function of shoot number relative to total leaf area; fewer shoots lead to more vigor exhibited per shoot. Vine fruitfulness is inversely related to the vigor of individual shoots.

Pruning should be done when vines are dormant, after leaf drop and before bud break (Smart and Robinson, 1991). However, pruning early in the dormant season may lead to winter injury in areas with significant frost, so generally pruning is done just prior to bud break (Goldammer, 2013). Balanced pruning techniques seek to find and maintain a vine’s balance between fruit yield and quality, and growth. Ideal cane growth should be approximately pencil size in diameter, strong, and not excessive in vigor. Weak canes indicate retention of too many buds and should be taken into account next season. Similarly, canes of a diameter greater than thumb size indicate excessive vigor because of too few buds retained.

Over-cropping and under-cropping may occur as a result of mismanaged vines (Smart and Robinson, 1991). Over-cropping occurs when too many buds are left at dormant pruning leading to issues with berry maturation. Berries may be delayed in reaching acceptable sugar levels that can cause harvest delay and other complications (Goldammer, 2013). Delayed harvest under hot conditions may result in a flat tasting wine, lacking acidity. Along with berry issues, over-cropping may negatively impact vine growth the following season. Under-cropping can reduce yields that can result from retaining too few buds. When too few buds are kept, canes may be too vigorous, and fruit production insufficient (Winkler, 1962). Along with yield reduction, over-cropping may create a microclimate that leads to poor fruit ripening and a canopy too densely shaded with vigorous canes creating conditions that promote disease development.

There are many metrics to evaluate vine balance. Three commonly used methods to achieve vine balance in terms of fruit quality and yield and vine growth are known as average cane weight, pruning formula, and the Ravaz index (Goldammer, 2013). Average cane weight is a calculation of the mean pruned cane weight and is used as an indication of vigor. Pruning formulas vary by variety, and consists of retaining a certain number of fruiting canes for the first pound of pruning weight followed by retaining an additional number of canes for each additional pound of pruning weight. For French American hybrids, this generally means 10 to 20 canes are retained for the first pound of pruning weight with an additional 10 canes retained for each pound after that. An established French American hybrid vine that had 4 pounds of pruning weight would warrant 20+10+10+10= 50 canes retained. Varieties of *V. vinifera* generally are in the range of 20 canes for the first pound and 20 canes for every pound pruned after that. The concept of the formula dictates that large vines should have more buds than smaller vines. In climates with severe risk of frost injury, additional buds should be retained as a buffer. The Ravaz index is an alternative ratio used to determine vine balance; it is a ratio of fruit yield to prune weight where the pounds of fruit harvested per vine in the previous year is divided by the pounds of prune weight per vine in the current year. Ideal ratios vary by region and variety, but generally a yield to prune weight ratio should be between 5 and 10 to limit vine vigor and encourage productivity. A ratio below 5 indicates more crop than what was harvested is possible and dictates an increase in bud number per vine. Conversely, a ratio of greater than 10 shows that crop thinning or bud reduction may be necessary. Measurements at pruning and harvest are important to anticipate the necessary steps to take in the following season to encourage or discourage growth as is deemed necessary (Smart and Robinson, 1991).

Breeding of grape vines is conducted for many purposes including to increase tolerance and resistance to abiotic factors (salinity, drought, heat, cold, etc.), to increase resistance to biotic pathogens and pests, to increase yield, or to alter the physical and chemical make-up of fruits for improved quality (Alleweldt and Possingham, 1988; Chittaranjan, 2011). Traditional breeding takes advantage of the sexual stage of each vine; because most of the commercially cultivated varieties of *V. vinifera* are naturally hermaphroditic, an emasculation stage is necessary to prevent self-pollination (Chittaranjan, 2011).

Grape breeding programs around the world are generally developed with the goal of creating new cultivars or rootstocks that are adapted to regional climates, resistant to pests or diseases, or have increased quality or novel traits. Following the introduction of North American pests and diseases (phylloxera and downy mildew) to Europe, French-American grape breeding programs such as those of Bertille Seyve and Victor Villard produced the cultivars ‘Seyval blanc’, ‘Villard blanc’, and ‘Villard noir’ using *V. vinifera* parents for quality traits and North American *Vitis* such as *V. rupestris* for crucial resistance traits (Reynolds, 2015). Interespecific crosses among North American *Vitis* were used in Austria, Italy, Hungary, and other European countries to produce rootstock cultivars capable of survival in phylloxera infested soils.

In the Southeastern U.S., breeding programs have focused on incorporating regional *Vitis* spp. germplasm to increase vine survivability amid PD and other fungal diseases prevalent in the Deep South. ‘MidSouth’, ‘Miss Blue’, and ‘Miss Blanc’ are three prime examples of Mississippi State University bred grapevines for the purpose of juice (Overcash et al., 1981; 1982; Stafne, 2016). They incorporate native species such as *V. aestivalis, V. labrusca*, *V. champini, V. rupestris,* and *V. berlandieri* to gain critical resistances (Stafne, 2016). The breeding program of the University of Florida Research Center at Leesburg and Apopka, FL produced numerous grape cultivars targeted for production under high PD pressure including ‘Conquistador’, ‘Stover’, ‘Suwannee’, ‘Daytona’, ‘Blanc du Bois’, ‘Lake Emerald’, and a muscadine containing *V. vinifera* parentage, ‘Southern Home’ (Halbrooks and Mortensen, 1989; Mortensen et al., 1994).

In the humid subtropical climate of the Southeast United States, commercial cultivation of European wine grapes, *V. vinifera*, has largely been prevented by the presence of PD, a bacterial infection caused by *Xylella fastidiosa* Wells et al. (*X.f.*), a gram negative bacterium endemic to the region and limited to the plant’s xylem (Hopkins and Purcell, 2002; Fritschi et al., 2007; Wells et al., 1987). The strains of *X.f.* known to cause PD of grapes are native to North and Central America, though the species also causes worldwide issues such as phony peach disease and plum leaf scorch in the genus *Prunus*, citrus variegated leaf chlorosis in the genus *Citrus*, and, under the overarching term bacterial leaf scorch, throughout kingdom Plantae (Hopkins and Purcell, 2002; Su et al., 2013). In regions of the Eastern United States with colder winter temperatures, PD infections are less severe; due to the exceptionally mild winters of the Southeast however, the bacterium is regionally more effective at overwintering and remains a consistent issue for growers (Feil and Purcell, 2001).

X.f. bacterial infection occurs through a variety of insect vectors; any sucking insect consuming xylem sap may serve as a vector for the bacterium (Almeida et al., 2005; Almeida, 2007). The bacterium is readily obtained when a sucking insect feeds upon a previously infected plant; the bacterium is subsequently transmitted to other plants on which the insect feeds (Almeida, 2007). For *X.f.*, all acknowledged vectors are found within the Order Hemiptera: suborder Auchenorrhyncha with the majority being placed in the family Cicadellideae. Insect vectors harboring *X.f.* bacterium are an efficient means of transferring PD between vines and other hosts (Hu, 2013). All known vectors are piercing sucking insects. Though spittlebugs of Cercopidae can transmit PD, the most notable vectors are known as sharpshooters, a specific kind of leaf hopper from the family Cicadellidae. Glassy-winged sharpshooters, *Homalodisca vitripennis* Germar, are widely acknowledge as a vector of PD, but other sharpshooters that may carry PD include the green sharpshooter (*Draculacephala minerva* Ball), the blue-green sharpshooter (*Graphocephala atropunctata* Signoret), and the red-headed sharpshooter (*Carneocephala fulgida* Nottingham) (Goldammer, 2013). Sharpshooters feed on young grape leaves by puncturing and sucking; they may leave a residual “honeydew” of excrement. Leafhoppers are believed to only transmit bacterium for vine-to-vine infection during summer. Limiting vectors through reduction of sharpshooters and hosts may reduce overall bacterial load; eliminating alternative hosts, like blackberries and elderberries can limit bacterial breeding sites.

Following transmittance of the bacterium to a healthy plant, *X.f.* is believed to build a biofilm within the xylem by using xylem sap as a source of nutrients, thus clogging and preventing the conductance of water throughout the plant (Hopkins and Purcell, 2002; Stevenson et al., 2005). This blockage of vascular tissue leads to many of the typical leaf scorching symptoms associated with the disease. Recent work has indicated that PD pathogenesis may be related to LesA, a newly discovered secreted lipase/esterase enzyme similar to LipA of *Xanthamonas* sp., with hypersensitive responses occurring in grapevine leaves with accumulated LesA (Nascimento et al., 2016).

Being fatal to most *V. vinifera* dominant cultivars, spring symptoms of PD become apparent early in the season when new growth is late to bud out and new leaves are yellow, malformed, or stunted. Inter-vein areas may be yellow, appearing similar to Zn deficiency (Jackson, 2008). Though sometimes a vine may recover over the winter following sufficient curative chilling, when vines are infected early in the season the likelihood of their recovery greatly diminishes (Anas et al., 2008; Krivanek et al., 2006). As the growing season progresses into fall and summer, symptoms tend to become more drastic and noticeable (Stevenson et al., 2005). The issues caused by PD may be initially confused with Zn deficiency, salt burn, or esca, black grape measles. A yellow to red discoloration of the leaf may occur, typically starting at the leaf margin and progressing inwards, leaving behind dead scorched tissue, ultimately leading to the entire leaf blade browning and falling off with the petiole remaining in what is known as a leaf "matchstick," due to visible similarity. Infection is followed by plant death in 1-5 years depending on severity.

Bunch grapes (*Vitis* sp.) represent an economically and culturally important fruit crop with global production increasing from 63 million metric tons in 2003 to over 77 million tons in 2013, a 22% increase (FAOSTAT, 2013). In the U.S., production exceeded 8 million metric tons in 2015 (USDA-NASS, 2016). In the Southeastern U.S., bunch grape production is limited by PD (Hopkins and Purcell, 2002; Wells et al., 1987). As a result, Alabama's viticulture industry has developed around the cultivation of PD resistant hybrid bunch grapes and muscadine grapes. Increasing local interest in grape production is evident in the number of bearing acres in Alabama that grew from 215 in 2002 to 426 in 2012, a 98% increase (USDA-NASS, 2016).

Along with Alabama, other southeastern states of Florida, Georgia, and Tennessee have seen 113%, 69%, and 158% increases, respectively, in production acreage in the same period of time, though Louisiana and Mississippi reduced acreage by 30% and 51%, respectively. Increases have occurred in the number of vineyard operations with acres bearing in Alabama, Florida, Louisiana, Mississippi, and Tennessee. Only Georgia had a modest reduction in operation number with a 5% decrease from 2007 to 2012.

Survey based production data for Georgia from 2007 to 2015 indicated that total tonnage of grapes produced increased from 2,900 tons to 4,950 tons without a decline in price per ton (USDA-NASS, 2016). Price received per ton grew from $1,060 to $1,510 with an average price of $1,266 over the eight year span. An average of 2.9 tons were harvested per acre in the survey period; 2007 reported 2.4 tons per acre and 2015 reported 3.3 tons per acre.

Developing PD resistant plants is critical for the cultivation of *V. vinifera* in the Southeast U.S. and for the longevity of the crop in regions, including California, where the glassy winged sharpshooter and causal bacteria were attributed with destruction of vineyards (Krivanek and Walker, 2005; Krivanek et al., 2006; Fritschi et al., 2007). *M. rotundifolia* has natural resistance or tolerance to PD, having evolved alongside the bacteria; however, as a result of its distant relationship with the European wine grape, *V.vinifera*, crosses have difficulty in producing fruitful and fertile progeny, though promise remains for rootstock breeding between the two genera (Ruel and Walker, 2006; Keller, 2010). Other native vines from North America have developed in conjunction with the bacteria, including *V. arizonica* and *V. candicans*. These vines readily hybridize within the genus *Vitis* (Keller, 2010; Chittaranjan, 2011). Resistance to PD is believed to be dominant in genetic expression (Krivanek et al., 2006). PdR1, the major gene involved with wild germplasm expressing resistance, is transferred from parent to progeny by Mendelian inheritance and is controlled by a dominant allele (Krivanek et al., 2006; Riaz et al., 2008). Polygenic inheritance of other genes involved in PD resistance is known, but less well understood (Krivanek et al., 2006). The current PdR1 genotype is derived from a *V. arizonica/ V. candicans* wild type plant growing in Monterrey, Mexico.

In response to PD’s economic threat, the UC Davis grape breeding program has developed PD resistant *V. vinifera* selections, three of which were planted in fall of 2010 at the

Chilton Research and Extension Center (CREC) to determine the feasibility of growing PD resistant *V. vinifera* in a high PD risk zone (Coneva, 2016; Ma, 2010; Riaz et al., 2008; Walker and Tenscher, 2010). These recently bred 87.5% *V. vinifera* selections, with dominant expression of the PdR1 gene discovered in a native *Vitis* selection, *V. arizonica* (Munson) collected near Nuevo Leon, Monterey, Mexico, have exhibited continued resistance to PD infection (Krivanek et al., 2006; Riaz et al., 2009). Due to overwhelming PD pressure as a result of abundant vectors, riparian locations, and a warm humid climate with a mild winter incapable of reducing PD populations, *V. vinifera* vines have previously performed unsuccessfully in Alabama. Growers have, until now, utilized primarily hybrid bunch grapes and *Vitis* relatives such as muscadines to produce table grapes and wines in the Southeast (Rombough, 2002). The native grapes produce wines that are generally considered inferior when compared to *V. vinifera* wines (Keller, 2010).

Assessing *V. vinifera* performance within the Southeastern U.S. has been severely limited by PD. As a result, little is understood about the developmental timing, vigor, fruit yield, or quality of *V. vinifera* vines grown in the humid subtropical environment of Alabama. While the diversity of Vitaceae has provided numerous native species adapted to the South’s various landscapes, few native grapevines offer the promise of quality found in European grapevines. Investigating details about the developmental and vegetative traits of PD resistant *V. vinifera* in the Southeast should uncovered a wide breadth of unique challenges beyond PD are likely to be uncovered.

It is critical to understand as much as possible about grape cultivar choice, environmental constraints, local terroir impact, and local pest and pathogen populations to produce the highest quality crop through environmentally and economically conscious production practices. In the Southeastern U.S. where PD pressure has previously limited production solely to muscadines and hybrid bunch grapes, grape growers understand the significance of grape cultivar choice for its role in vine survivability and vineyard longevity.

Little information is available on the performance of hybrid bunch grapes in Alabama's climate. While Hu (2013) characterized the growth and development of numerous wine, juice, and table American and French-American bunch grapes at Alabama's Sand Mountain Research Extension Center, Crossville, AL and North Alabama Horticultural Research Center, Cullman, AL, no studies were found to provide information on *V. vinifera* grapes in Alabama.

With very little known about the performance of *V. vinifera* grapes in the Southeast's climate, there is great opportunity to generate knowledge on the suitability and viticultural performance of UC Davis developed PD resistant selections. The CREC field study, and an analogous study conducted by Jim Kamas at Texas A&M, represent the first experimental field planting of the 87.5% *V. vinifera* selections within the high PD pressure zones of Alabama and Texas (Walker and Tenscher, 2010). Recently, 87.5% *V. vinifera* selections were obtained by two commercial vineyards located near Albertville, AL and Anniston, AL, representing the first Southeastern plantings of the UC-Davis bred PD resistant *V. vinifera* vines for the purpose of experimental commercial production. This further necessitates evaluation of these selections.

To enable Southeastern grape and wine producers to sustainably grow *V. vinifera* vines, establishing an understanding of *V. vinifera* cropping performance and quality is critical to successful industry expansion. Hypothesizing that PD resistant *V. vinifera* vines will successfully grow within the high PD pressure of Central Alabama, the objective for this study was to determine the phenological development, growth traits, yield potential, vine vigor, and fruit quality for the *V. vinifera* hybrid lines 'U0501-12', 'U0502-01', and 'U0502-10' when grown in a high PD risk zone (Anas et al., 2008; Ma, 2010).

Materials and Methods

Experimental Design

On December 9, 2010, an experimental vineyard was planted at the Chilton Research and Extension Center located in Chilton County, AL, (32°55’11.6” N, 86°40’25.4” W), USDA Plant Hardiness Zone 8A. The experimental design was a complete randomized block design with six blocks composed of five plants per block planted at a density of 519 vines per acre with 3.7 m between rows and 2.1 m between vines. Vines were grafted on PD resistant ‘Dog Ridge’ rootstock and planted into a Dothan fine-loam (kaolinitic, thermic Plinthic Kandiuudults) with soil pH adjusted to 6.2 prior to planting. A drip irrigation system was installed prior to planting and vines were irrigated as needed. Nutrition was provided according to standard commercial practices (Poling, 2007). Vines were trained to a Vertical Shoot Positioning (VSP) system with three catch wires. Pest management practices followed regional recommendations for commercial bunch grape production (Nita et al., 2016).

Phenology

Phenological stages of vine early shoot growth and fruit maturation were evaluated using the Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie (BBCH) scale (Lorenz et al., 1995). On each vine, two shoots at the basal and distal regions of each cordon were selected and flagged for monitoring and data collection resulting in a total number of four shoots per vine. Bud development and early season shoot and canopy development were monitored for leaf emergence and shoot growth. Phenological development was recorded on weekly.

Flowering was monitored in spring to determine the critical flowering stages. Floraison was estimated to have occurred when 50% of flowers per fruiting cluster were open. Development of fruit was monitored as berries progressed from fruit set to berry touch stages. Veraison and ripening of berries was assessed throughout the changes in berry color and fruit softening.

To determine veraison progression, percent berries changing color was visually rated using a 0-100 scale for each vine as a percentage of berries per vine turning from an immature green to mature coloration. Ratings were conducted weekly in late June until 100% of berries turned color.

Vegetative Characteristics

Data was collected to determine the vine vigor and vegetative growth characteristics of each selection. Vine vigor was determined by measuring vine dormant pruning weight and trunk cross sectional area (TCSA). Annual dormant pruning was conducted in early spring. Pruned canes weight was measured for each individual vine using an Adam CPWplus-35 (Adam Equipment Inc., Danbury CT) scale. Vines were pruned to retain seven to eight spurs per cordon with two buds per spur for a total of fifteen fruiting spurs per plant and a total number of 30 buds per vine according to the balanced pruning theory (Smart and Robinson, 1991). Trunk diameter was measured for each vine at 25 cm above the graft union using a digital caliper, and then the TCSA was calculated as $\pi \times (d/2)^2$.

Foliar characteristics evaluated included leaf area, leaf chlorophyll content, and photosynthetic CO_2 assimilation rates (Pn). Single leaf area was measured by collecting five recently matured leaves per vine for a total number of 30 leaves per replication. Recently matured leaves were collected at random from the interior and exterior portions of the canopy during midsummer, at a minimum distance of five nodes below the terminal bud. Leaf area was measured using a Licor LI-3100 area meter (Licor Inc., Lincoln, NB, USA).

Leaf chlorophyll content was measured on ten recently matured leaves per vine. Leaf chlorophyll content was measured using a SPAD-502 Plus chlorophyll meter (Konica Minolta Sensing, INC, Osaka, Japan).

To obtain Pn rates for each selection, measurements were conducted at midday (1100-1400 HR) when stomatal opening and photosynthesis was at a maximum rate. Photosynthetic rates and stomatal conductance were measured using a Portable Photosynthesis System, TPS-2 (PP Systems, Amesbury, MA). Leaves used for measurements were recently mature primary leaves located five or more nodes below the terminal bud and fully exposed to sunlight. Leaves were enclosed in the PLC4 (B) Broad Leaf Cuvette (ADC Ltd., Hoddeson, England) and allowed to equilibrate for 1 minute prior to data collection. A total of one leaf per plant was evaluated for a cumulative sample of five leaves per replication. Evaluation was conducted each year prior to crop harvest.

Fruit Characteristics

Total yield per vine was measured at harvest for each experimental vine. Harvest was conducted by hand. Total number of fruit clusters per vine was recorded at harvest. Two subsamples were collected for each vine. Five clusters per vine were collected to determine average cluster weight, and average berry weight was determined based on a 50-berry subsample per vine using a digital scale (Adventurer Pro AV4101, Ohaus Corp., Pine Brook, NJ, U.S.A). Following harvest evaluations, grape berries were maintained in a 4 ℃ cooler until fruit quality analysis was conducted. Two harvest metrics were calculated; growth-yield relationship (this year’s yield per vine [kg] divided by this year’s dormant pruning wood per vine [kg]) and Ravaz index (this year’s yield per vine [kg] divided by next year’s dormant pruning wood per vine [kg]).

Fruit quality analysis was conducted to evaluate berry pH, titratable acidity (TA), and soluble solid content (SSC) using a 50-berry subsample. Grapes were crushed with mortar and pestle, filtered through cheesecloth, and juice was stored in nonreactive glassware at 4 ℃ until further analysis. Berry pH was measured using an Accumet Basic AB 15 pH meter (Fisher Scientific, Hampton, NH). To measure TA, a one mL sample of grape juice was diluted to 40 mL of solution using deionized water. Titration was conducted to an endpoint of pH 8.2 using a 0.1 N NaOH titrant solution in a DL 15 Titrator (Mettler-Toledo LLC, Columbus, OH). Results were recorded as grams of tartaric acid equivalent per liter of juice. SSC was measured at room temperature using extracted juice analyzed using a digital refractometer (Pal-1; Atago Co., Tokyo, Japan) and expressed as Brix (°B). Brix:TA ratio was calculated by dividing the SSC by the TA g/L (Goldammer, 2013). An additional metric for grape ripeness, $pH^2 \times Brix$, was also calculated (Coombe et al., 1980).

Pierce’s Disease Symptoms

Vines were visually assessed for PD symptoms including scorching, matchstick, and green island symptomatology. Visual ratings were conducted following the harvest of each crop on a scale from 0 to 5 where 0 = no visible symptoms; 1 = 1 to 20% leaves exhibiting symptoms; 2 = 21 to 40% leaves exhibiting symptoms; 3 = 41 to 60% leaves exhibiting symptoms; 4 = 61 to 80% leaves exhibiting symptoms; 5 = 81 to 100% leaves exhibiting symptoms.

Statistical Analysis

Analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Cary, NC). The experimental design was a split-split plot with selection in the main plot, spur location in the sub-plot, and date in the sub-sub-plot for early season leaf emergence, length of early season shoots, open flower rating, and veraison. The experimental design was a split plot with year in the main plot and selection in the sub-plot for dormant pruning weight, trunk cross-sectional-area, chlorophyll content, leaf area, photosynthesis rate, clusters per vine, total yield per vine, cluster weight, growth-yield relationship, and Ravaz index. The experimental design was a randomized complete block for berry weight, pH, titratable acidity, Brix, Brix:titratable acidity ratio, and pH2×(Brix). Where residual plots and a significant COVTEST statement using the HOMOGENEITY option indicated heterogeneous variance among treatments, a RANDOM statement with the GROUP option was used to correct heterogeneity. Differences among selections and spur locations were determined using the Shaffer-simulated method. Flower percent ratings were analyzed using the multinomial probability distribution, and data presented are medians. Differences among spur locations were determined using ESTIMATE statements. Linear and quadratic trends over dates were determined using orthogonal polynomials for all responses. All significances were at $\alpha = 0.05$.

Results

Phenology

All selections completed dormancy stage by the end of March, when the new shoots started to emerge with quadratic trends over time in 2015 and linear trends over time in 2016 (Table 2.1). In both study years, all selections had more than ten leaves emerged per shoot by the end of April. A difference was found in early shoot emergence among buds at different spur locations on 8 Apr. in both years when shoots on basal spurs developed earlier than those formed on distal spurs. Differences in shoot development were not detected at any other event during canopy formation.

In both years, ‘U0502-10’ was the fastest selection to develop the canopy, as measured by vine shoot length with linear trends over time in 2015 and quadratic trends over time in 2016 (Table 2.2). Shoots on ‘U0501-12’ had delayed growth early in the season when compared to the other two selections. By mid-April, shoot length of ‘U0501-12’was similar to the length of ‘U0502-01’ in both years.

Flowering was initiated earliest than the other two selections for ‘U0502-01’ in 2015 (Table 2.3). Flowering had a quadratic trend over time for all selections in both years except ‘U0502-01’ that had a linear trend over time in 2015. All selections were considered in full bloom stage when greater than 50% of flowers had opened. Full bloom stage occurred by 6 May 2015 and by 10 May 2016.

Veraison and harvest dates showed differences in phenological development among the selections (Tables 2.4 and 2.5). Berries of ‘U0502-10’ initiated veraison stage at the end of June and completed veraison by late July. Selection ‘U0502-10’ was harvested on 14 Aug. 2015 when the clusters of ‘U0502-01’ had less than 50% of berries turning color, and selection ‘U0501-12’ was harvested on 23 Oct. 2015, or 70 days later. ‘U0502-01’ was the latest selection to ripen, and was harvested on 30 Oct. 2015. Berry veraison had a cubic trend over time for ‘U0502-01’ in

2016, and it was quadratic over time at all other instances. In both years of our study, selections followed the same veraison initiation order with ‘U0502-10’ starting in late June, followed by ‘U0502-01’, and ‘U0501-12’. ‘U0502-10’ was the first harvested selection on 29 Aug. 2016, followed by ‘U0502-01’ on 20 Sept. 2016, and ‘U0501-12’ was harvested last on 12 Oct. 2016.

Vegetative Characteristics

Dormant pruning weight was greatest for ‘U0501-12’ and ‘U0502-01’ in 2015, while in 2016, ‘U0501-12’ had the greatest pruning weight (Table 2.6). In 2015, all selections’ pruning weights exceeded 1.8 kg, while in 2016 all pruning weights were over 2.4 kg. Contrastingly, despite having the highest pruning weight in both years, ‘U0501-12’ had the lowest TCSA in both years (Table 2.7).

Grapevine physiological characteristics for the three tested selections were similar for Pn rate and chlorophyll levels based on foliar measurements (Table 2.8). Foliar characteristics only differed in leaf area with the largest leaves produced by ‘U0502-01’ and the smallest leaves by ‘U0502-10’ vines.

Fruit Characteristics

In 2015, ‘U0502-10’ had the largest weight, and fewest clusters per vine (Table 2.9). The other two selections had a similar number of clusters per vine, with ‘U0501-12’ producing the smallest cluster weight. In 2016, ‘U0501-12’ (Figure 2.1) produced the highest number of clusters/vine, followed by ‘U0502-01’ (Figure 2.2), and ‘U0502-10’ (Figure 2.3) had the lowest number of clusters. Although the total yield per vine was lowest for ‘U0501-12’, it averaged 11.1 t/ha. In both study years, ‘U0502-10’ produced the greatest yield.

The Ravaz index (RI) (2015 yield/vine divided by 2016 pruning weight/vine) for all three selections was between 3.1 and 4.5. An RI value between 5 and 10 was recommended as an indicator of good vine balance for *V. vinifera* cultivars, while an RI value greater than 10 suggests an over cropping situation. Growth-yield relationships, a measurement with similar parameters looking at a single year's growth (2015 yield/vine divided by 2015 pruning weight/vine), were between 4.4 and 6.2 for the three selections. 'U0502-10' had the greatest growth-yield relationship in 2015, while 'U0501-12' had the lowest.

Growth-yield relationships for the selections in 2016 again indicated that although the vines were highly productive in-terms of yield, they continued to produce sufficient to excess cane and shoot growth as complementary canopy. Growth-yield relationships in 2016 ranged from 3.0 to 5.5 with 'U0501-12' having the lowest value and 'U0502-10' having the highest value. Even though 'U0501-12' produced the lowest yield in 2016, it also produced the greatest pruning weights per vine, leading to a high growth-yield relationship value. Contrastingly, while producing 0.4 kg of pruning wood per vine less than 'U0501-12', 'U0502-10' produced 5.1 kg higher crop per vine, leading to the highest growth-yield relationship in 2016.

The three *V. vinifera* selections differ in their fruit quality characteristics. 'U0501-12' had the smallest berry weight, while 'U0502-01' had the largest berry weight in both years (Table 2.10). 'U0502-10' had the lowest pH and 'U0502-01' had the highest pH and the lowest TA in 2015. Selection 'U0502-10' had the lowest SSC, while 'U0501-12' had the highest SSC in both years of our study.

SSC was improved for all three selections in 2016, ranging from 18.6 to 23.1, with the 'U0501-12' having the greatest SSC. pH values were within range for red table wine production for the first two harvested selections (Boulton et al., 1996). TA values indicated all three selections were slightly below desirable values for red table wine. With an optimal range of 6.5 to 7.5 g/L, ‘U0501-12’ was nearest to ideal with 6.2 g/L and ‘U0502-01’ was farthest with 5.2 g/L. Concerning the sugar to acid ratio, Brix:TA, in 2016, ‘U0502-10’ was within range of a balanced value of 30-32 for a red table wine. For the pH^2×(Brix) value, all three selections fell below the target value of 245 or greater, but were within a desirable range for wine production 200 to 270.

Pierce’s Disease Symptomology

No PD symptoms were detected through visual rating for any of the three selections in either 2015 or 2016 (data not shown). To follow-up, leaf samples were submitted to the Auburn University Plant Diagnostic Lab and ELISA tests were conducted indicating no *X.f.* infection.

Discussion

The newly developed PD resistant selections evaluated in our study offer basic information for developmental patterns of *V. vinifera* in the high PD pressure environment of Central Alabama. Further understanding of *V. vinifera* vine canopy development and flowering time will aid in comparisons across different Southeastern environments in plantings where PD previously prevented phenological and physiological assessment of *V. vinifera* grapevines.

Selections ‘U0502-01’ and ‘U0502-10’ had relatively early shoot development that may have been derived from their most recent *V. vinifera* parent, ‘Chardonnay,’ for which bud break occurs earlier than average (McIntyre et al., 1982). The three selections began leaf emergence by early April in both years before the last threat of late spring frost in the area that, according to the Northeast Regional Climate Center (2016), has occurred in Clanton, AL as late as April 10th over the last 25 years. Modified pruning practices (double pruning, delayed spur-pruning, or long cane pruning) may have to be employed to delay budburst in high freeze risk years (Trought et al., 1999).

Period of flowering was similar for all three selections, occurring within the first 2 weeks of May each year. This finding agreed with the performance of the selections in California where all three selections bloomed within the first week of May in 2007 (Walker and Tenscher, 2008). While the bloom period for all studied selections was similar in both years, further monitoring of the vines may reveal that certain environmental conditions can result in different developmental patterns. Walker and Tenscher (2009) reported that blooming occurred 11 days later for 'U0501-12' when compared to 'U0502-10' in California in 2009.

The ripening season observed here was similar to the pattern observed in years prior to the initiation of this study in which 'U0501-12' was harvested on 20 Sept. 2012 and 10 Oct. 2013, 'U0502-01' was harvested on 11 Sept. 2012 and 10 Oct. 2013, and 'U0502-10' was harvested on 20 July 2012 and 27 Aug. 2013 (Coneva, 2016).

It will be important to understand the physiological processes involved in dormancy completion and early vine development for PD-resistant *V. vinifera* selections planted in the Southeast to be conscious and prepared for mitigating the late spring frost risks. Additionally, protecting the crop through a long growing season in the humid subtropical climate may encourage the investigation of methods to hasten ripening.

Estimated dormant pruning cane weight (dormant pruning weight divided by cane number) exceeded 60 g for 'U0501-12' and 'U0502-01' in 2015, indicating high vigor according to Kliewer and Casteel (2003). In 2016, estimated dormant cane weight was greater than 80 g for all studied selections, indicating high vine vigor.

Vine shoot topping was used to manage vine vigor from May through October resulting in subsequent expansion of lateral shoots in all selections. During the 2015 season, over thinning of laterals may have occurred as part of a precautionary action to prevent a microclimate within the canopy conducive to bunch rots and foliar pathogens.

Timing and severity of vine topping should be examined under different training systems. Shoot topping to a level of 15 to 20 leaves per shoot has been indicated as a sufficient canopy management practice in ‘Riesling’ grown in the humid and hot climate of Virginia, where topping to a level of 20 leaves per shoot resulted in fruit with the highest SSC and reduced incidence of fruit rot (Wolf et al., 1990).

Currently, the experimental vineyard is planted to a density of 2.1 m between vines and 3.7 m between rows. Planting density should be considered in future research trials as another means to facilitate vine cropping potential and balance vine vigor.

Pruning severity should also be investigated to maximize productivity. To this point, the vines have been cordon trained and spur-pruned to a level of 15 spurs per vine such that each spur consists of two buds for a total of 30 buds per vine. For the purpose of experimental design, the experimental vines have not had their crop load adjusted nor their bud number altered. Based on pruning weights in the 2015 and 2016 dormant seasons and balanced pruning theory, the vines may have considerably greater production potential. For a *V. vinifera* grape, it is recommended that 20 buds should be retained for the first pound of dormant pruning wood and 20 buds retained for each additional pound. In this case, the number of retained buds per vine would have ranged from 80 to 88 in 2015 and 106 to 128 in 2016. From the perspective of the grapevine canopy, higher number of buds retained would demand greater planting distance between vines to prevent excess crowding of fruiting canes. Alternatively, a divided canopy such as an open lyre, Watson trellis system, or a similar modified canopy architecture might be utilized to provide opportunity for greater bud retention per vine, while still allowing for sufficient spray penetration and optimal airflow without over shading the canopy and fruiting zones.

Estimated cluster number per cane (clusters per vine divided by 30 fruiting canes per vine) for ‘U0502-10’ was 0.9 in both years, indicating that slightly less than one cluster was produced for each bud retained. For the smaller clustered ‘U0501-12’, there was an estimated cluster number of 1.5 and 2.0 per fruiting cane, and for ‘U0502-01’ the cluster number per fruit cane was 1.6 and 1.7 in 2015 and 2016, respectively. These numbers and the relative fruitfulness of buds may be used to actively adjust crop level as early in the season as during the dormant pruning period, saving vine carbohydrates and labor costs.

Cluster thinning was not applied in either season, so crop load was not actively adjusted to optimize vine balance. RI values and growth-yield relationships both indicate the need to further refine definitions of canopy, crop load, and vine balance with these selections to ensure consistent and high quality yields that are economically feasible and sustainable from the perspective of vine health and longevity. ‘U0501-12’ and ‘U0502-01’ were harvested in the final weeks of October 2015. The ripening period for these two selections may have been directly delayed by either prematurely over-cropping the vines or by extensive lateral vegetation removal. Developing appropriate viticultural management practices for the Southeastern U.S. is critical to sustain viticultural viability. Further research is needed to evaluate best management practices including, but not limited to deficit irrigation, optimal planting density, training system, pruning practices, canopy management (shoot, leaf, and cluster thinning), and manipulation of vineyard microclimate.

RI values for the 2016 crop are not available until the dormant 2017 pruning season; as a result canopy and crop relations for the 2016 season have only been evaluated using the growth-yield relationship. It is expected that the RI values will help in the understanding of these three *V. vinifera* vine's performance in the Southeastern U.S.

This project was focused to thoroughly assess *V. vinifera* vine phenology, vigor, fruit quality, and cropping potential in the underexplored viticultural environment of Central Alabama. In the midst of high PD pressure prevalent in the Southeast, these three selections have shown very promising potential for high productivity, excellent fruit quality and PD resistance.

It is important to examine *V. vinifera* grown in the southern portion of the Eastern U.S. to understand the performance of the PD resistant 87.5% *V. vinifera* grown in AL. 'Cabernet Sauvignon' grown in the humid climate of Yadkin Valley, NC averaging 1000 mm of precipitation produced 0.86 kg/m of dormant pruning wood when grown with a conventional herbicide strip (Giese et al., 2015). The same vines produced yields of 5.1 kg/vine at a spacing of 2.74 × 1.83 m with a SSC of 21.6 % from 2007 to 2009 and 19.9 % during 2010 and 2011. In 2016, 'U0501-12', produced 1.4 kg/m of dormant pruning wood and all vines exceed 0.8 kg/m. Giese et al. (2015) applied hedging twice during the growing season while the three selections evaluated at CREC required routine monthly hedging to prevent canopy shading. The applied hedging practiced at CREC as well as variation in environment, selections' vigor, and other cultural practices may account for variation in pruning weights.

In another humid environment vineyard of 'Cabernet Sauvignon' planted near Winchester, VA, Hickey et al. (2016) found that vines maintained with an herbicide treated strip produced 1.01 kg/m pruning weights and 4.47 kg/vine of fruit yield with a Growth-yield relationship of 3.02 for the crop load. The Growth-yield relationship was lowest (3.0) for our most vigorous selection, ‘U0501-12’ in 2016, and at all other times the Growth-yield relationship was greater than 4.3 for the PD resistant *V. vinifera* selections in AL. Crop load management was not applied for the experimental vines at CREC. Cluster thinning is often applied in *V. vinifera* production in humid environments and may be examined in future studies (Giese et al, 2015; Hatch et al., 2011; Hickey et al., 2016).

Yield for the three PD resistant 87.5% *V. vinifera* selections has ranged from 4.3 t/a for ‘U0501-12’ to 7.0 t/a for ‘U0502-10’, well within range of *V. vinifera* production regions of the Eastern and Western U.S. The studied *V. vinifera* selections have excellent fruit quality and potential for wine (Walker and Tenscher, 2010). Planting density, cultural practices, training systems, deficit irrigation, and site selection may be examined as methods to maximize fruit quality potential of PD resistant *V. vinifera* in the Southeast. These results and previous studies in our lab (Coneva, 2016) indicate the excellent prospects for *V. vinifera* production in Alabama. While this particular study was concluded before the plants were completely established in the field (five and six years old), it is possible that fruit yield quantity and quality may still increase for one or more selections in the future as the vines become fully mature.

Literature Cited

Alleweldt, G. and J. Possingham. 1988. Progress in grapevine breeding. Theor. Appl. Genet. 75(5): 669–673.

Almeida, R.P. 2007. Glassy-winged sharpshooter transmission of *Xylella fastidiosa* to plants. Proc.Hawaiin Entomol. Soc. 39: 83–96.

Almeida, R.P.P., C. Wistrom, B.L. Hill, J. Hashim, and A.H. Purcell. 2005. Vector transmission of Xylella fastidiosa to dormant grape. Plant Dis. 89: 419–424.

Anas, O., U.J. Harrison, P.M. Brannen, and T.B. Sutton. 2008. The effect of warming winter temperatures on the severity of Pierce's disease in the Appalachian mountains and Piedmont of the southeastern United States. Online. Plant Health Progress doi:10.1094/PHP-2008-0718-01-RS.

Boulton, B., V.L. Singleton, L.F. Bisson, and R.E. Kunkee. 1996. Principles and practices of winemaking. Chapman and Hall. New York, New York.

Chittaranjan, K. (ed.). 2011. Genetics, Genomics, and Breeding of Grapes. Science Publishers. Boca Raton, FL.

Coneva, E. 2016. Growing Pierce's disease resistant 87.5% *V. vinifera* grapes in Alabama. Acta Hort. 1115:75-82

Coombe, B.G., R.J. Dundon, and A.W.S. Short. 1980. Indices of sugar—acidity as ripeness criteria for winegrapes. J. Sci. Food Agric. 31: 495–502.

Dry, P.R. 2000. Canopy management for fruitfulness. Aust. J. Grape Wine Res. 6: 109–115.

FAOSTAT. 2013. Food and Agriculture Organization of the United Nations. May 2016. <www.faostat3.fao.org/>.

Feil, H. and A.H. Purcell. 2001. Temperature-dependent growth and survival of *Xylella* *fastidiosa* in vitro and in potted grapevines. Plant Dis. 85: 1230–1234.

Fritschi, F.B., H. Lin, and M.A. Walker. 2007. *Xylella fastidiosa* population dynamics in grapevine genotypes differing in susceptibility to Pierce's Disease. Am. J. Enol. Viticult. 58: 326–332.

Giese, G., T.K. Wolf, C. Velasco-Cruz, L. Roberts, and J. Heitman. 2015. Cover crop and root pruning impacts on vegetative growth, crop yield components, and grape composition of Cabernet Sauvignon. Amer. J. Enol. Viticult. 66: 212-226.

Goldammer T. 2013. Grape grower's handbook. A complete guide to viticulture for wine production. Apex Publishers. Centreville, VA.

Halbrooks, M. C. and J.A. Mortensen. 1989. Origin and significance of Florida hybrid bunch grapes and rootstocks. HortScience 24:546-550.

Hatch, T.A., C.C. Hickey, and T.K. Wolf. 2011. Cover crop, rootstock, and root restriction regulate vegetative growth of Cabernet Sauvignon in a humid environment. *Amer. J. Enol. Viticult.* 62*:*298–311.

Hickey, C.C., T.A. Hatch, J. Stallings, and T. K. Wolf. 2016. Under-trellis cover crop and rootstock alter growth, components of yield, and fruit composition of Cabernet Sauvignon. Amer. J. Enol. Viticult. 67: 281-295.

Hopkins, D.L., and A.H. Purcell. 2002. *Xylella fastidiosa*: cause of Pierce's disease of grapevine and other emergent diseases. Plant Dis. 86(10): 1056–1066.

Hu, Y. 2013. Feasibility of growing Pierce's disease tolerant American and French-American hybrid bunch grape cultivars and advanced grape selections in Alabama. Auburn Univ. Thesis.

Jackson, R.S. 2008. Wine science: Principles and applications. Academic Press. Burlington, Massachusetts.

Keller, M. 2010. The Science of Grapevines: Anatomy and Physiology. Academic Press. Burlington, MA.

Kliewer, W.M. and T. Casteel. 2003. Canopy management. In Oregon Viticulture. E. Hellman (ed.), pp. 177-184. Oregon State University Press, Corvallis, OR.

Krivanek, A.F., S. Riaz, and M.A. Walker. 2006. Identification and molecular mapping of PdR1, a primary resistance gene to Pierce's disease in *Vitis*. Theor. Appl. Genet. 112: 1125–1131.

Krivanek, A.F. and M.A. Walker. 2005. *Vitis* resistance to Pierce's disease is characterized by differential *Xylella fastidiosa* populations in stems and leaves. Phytopathol. 95: 44–52.

Lorenz, D.H., K.W. Eichhorn, H. Bleiholder, R. Klose, U. Meier, and E. Weber. 1995. Growth stages of the grapevine: phenological growth stages of the grapevine (*Vitis vinifera* L. ssp. vinifera)—codes and descriptions according to the extended BBCH scale. Australian J. of Grape and Wine Res. 1: 100-103.

Ma, X. 2010. The occurrence of *Xylella fastidiosa* and its sharpshooter vectors in selected Alabama orchards and vineyards. Auburn Univ. Thesis.

McIntyre, G.N., L.A. Lider, and N.L. Ferrari. 1982. The chronological classification of grapevine phenology. Amer. J. of Enol. and Viticult. 33:80-85.

Mortensen, J. A., J. W. Harris, D. L. Hopkins, and P. C. Andersen. 1994. 'Southern Home': An interspecific hybrid grape with ornamental value. HortScience 29:1371-1372.

Mullins, M.G., A. Bouquet, and L.E. Williams. 1992. Biology of the grapevine. Cambridge University Press. Cambridge, United Kingdom.

Myles, S., A.R. Boyko, C.L. Owens, P.J. Brown, F. Grassi, M.K. Aradhya, B. Prins, A. Reynolds, J. M. Chia, D. Ware, C.D. Bustamante, and E.S. Buckler. 2011. Genetic structure and domestication history of the grape. Proc. Natl. Acad. Sci. 108: 3530–3535.

Nascimento R., H. Gouran, S. Chakraborty, H.W. Gillespie, H.O. Almeida-Souza, A. Tu, B.J. Rao, P.A. Feldstein, G. Bruening, L.R. Goulart, and A.M. Dandekar. 2016. The type II secreted lipase/esterase LesA is a key virulence factor required for *Xylella fastidiosa* pathogenesis in grapevines. Sci. Rep.18598. doi: 10.1038/srep18598.

Northeast Regional Climate Center. 2016. Northeast RCC CLIMOD II. Cornell University and <National Oceanic and Atmospheric Administration. http://climodtest.nrcc.cornell.edu/>.

Nita, M., H. Burrack, D. Pfeiffer, W. Mitchem, D. Lockwood, B. Bellinger, P. Brannen, P. Smith. 2016. 2016 Southeast regional bunch grape integrated management guide. Southern Region Small Fruit Consortium. <http://www.smallfruits.org/smallfruitsregguide/Guides/2016/BunchGrapeSprayGuide2016.pdf>.

Overcash, J.P., C.P. Hegwood, and B.J. Stojanovic. 1981. ‘MidSouth’ and ‘Miss Blue’ – two new bunch grape cultivars. Miss. Ag. & For. Expt. Sta. Res. Rep. 6(18).

Overcash, J.P., C.P. Hegwood, and B.J. Stojanovic. 1982. ‘Miss Blanc’ a new bunch grape cultivar. Miss. Ag. & For. Expt. Sta. Bull. No. 909.

Poling, E.B. (ed.) 2007. North Carolina wine grape grower's guide. NC Cooperative Extension Service. 535.

Reynolds, A.G. 2015. Grapevine breeding in France- a historical perspective. p. 65-76. In: A.G. Reynolds (ed.). Grapevine breeding programs for the wine industry. Woodhead Publishing Ltd., Cambridge, UK.

Riaz, S., A.C. Tenscher, J. Rubin, R. Graziani, S.S. Pao, and M.A. Walker. 2008. Fine-scale genetic mapping of two Pierce’s disease resistance loci and a major segregation distortion region on chromosome 14 of grape. Theor. Appl. Genet. 117: 671–681.

Rombough, L. 2002. The grape grower: A guide to organic viticulture. Chelsea Green Publishing. White River Junction, VT.

Ruel, J.J. and A.M. Walker. 2006. Resistance to Pierce’s Disease in *Muscadinia rotundifolia* and other native grape species. Am. J. Enol. Viticult. 57: 158–165.

Smart, R. and M. Robinson. 1991. Sunlight into wine: A handbook for winegrape canopy management. Winetitles. Adelaide, Australia.

Stafne, E. 2016. A history of bunch grapes research in Mississippi. J. of the Amer. Pom. Soc. 70: 158-164.

Stevenson, J.F., M.A. Matthews, and T.L. Rost. 2005. The developmental anatomy of Pierce’s disease symptoms in grapevines: green islands and matchsticks. Plant Dis. 89: 543–548.

Su, C.C., C.J. Chang, C.M. Chang, H.T. Shih, K.C. Tzeng, F.J. Jan, C.W. Kao, and W.L. Deng. 2013. Pierce’s disease of grapevines in Taiwan: Isolation, cultivation and pathogenicity of *Xylella fastidiosa*. J. Phytopathol. 161: 389–396.

Terral, J. F., E. Tabard, L. Bouby, S. Ivorra, T. Pastor, I. Figueiral, S. Picq, J. B. Chevance, C. Jung, L. Fabre, C. Tardy, M. Compan, R. Bacilieri, T. Lacombe, and P. This. 010. Evolution and history of grapevine (*Vitis vinifera*) under domestication: new morphometric perspectives to understand seed domestication syndrome and reveal origins of ancient European cultivars. Ann. Bot. 105: 443–455.

This, P., T. Lacombe, and M.R. Thomas. 2006. Historical origins and genetic diversity of wine grapes. Trends Genet. 22: 511–519.

Trought, M.C., G.S. Howell, and N.J. Cherry, 1999. Practical considerations for reducing frost damage in vineyards.

USDA-NASS. 2016. Census of agricultural-state data. USDA Nat. Agr. Stat. Serv. May 2016. <https://www.nass. usda.gov/>.

Walker, M.A. and A. Tenscher. 2008. Breeding Pierce's disease resistant winegrapes. Proc. Pierce's Dis. Res. Symp. 248-253.

Walker, M.A. and A. Tenscher. 2009. Breeding Pierce's disease resistant winegrapes. Proc. Pierce's Dis. Res. Symp. 197-203.

Walker, M.A. and A. Tenscher. 2010. Breeding Pierce's disease resistant winegrapes. Proc. Pierce's Dis. Res. Symp. 255-260.

Wells, J.M., B.C. Raju, H.Y. Hung, W.G. Weisburg, L. Mandelco-Paul, and D.J. Brenner. 1987. *Xylella fastidiosa* gen. nov., sp. nov: gram-negative, xylem- limited, fastidious plant bacteria related to *Xanthomonas* spp. Intl. J. Systematic and Evolutionary Microbiol.37: 136-143.

Winkler, A.J. 1962. General viticulture. University of California Press. Berkeley, CA.

Wolf, T.K., B.W. Zoecklein, M.K. Cook, and C.K. Cottingham. 1990. Shoot topping and ethephon effects on white Riesling grapes and grapevines. Amer. J. Enol. Viticult. 41: 330-341.

Table 2.1. Early season leaf emergence of Pierce's disease resistant 87.5% *Vitis vinifera* selections grown at the Chilton Research and Extension Center, Clanton, AL, 2015-2016.[z]

	Leaf emergence no.				
	2015				
Selection	30 Mar.	8 Apr.	14 Apr.	20 Apr.	Sign.[y]
'U0501-12'	0 c[x]	5 ns	9 b	10 ns	Q***
'U0502-01'	2 a	5	10 a	10	Q***
'U0502-10'	1 b	5	10 a	10	Q***
Spur location					
Basal	1 ns	5 a	10 ns	10 ns	Q***
Distal	1	5 b	10	10	Q***
	2016				
	30 Mar.	8 Apr.	15 Apr.	25 Apr.	Sign.
'U0501-12'	0 c	4 b	6 c	10 ns	Q*
'U0502-01'	1 b	5 a	8 b	10	Q***
'U0502-10'	2 a	5 a	9 a	10	Q***
Spur location					
Basal	1 ns	5 a	8 ns	10 ns	Q***
Distal	1	5 b	8	10	Q***

[z] The selection by date and spur location by date interactions were significant at α = 0.05 in both years.

[y] Significant (Sign.) quadratic (Q) trends using orthogonal polynomials at α = 0.05 (*) or 0.001 (***).

[x] Least squares means comparisons among selections and spur locations (lower case in columns) using the Shaffer-simulated method at α = 0.05. ns = not significant.

Table 2.2. Length of early season shoot growth of Pierce’s disease resistant 87.5% *Vitis vinifera* selections grown at the Chilton Research and Extension Center, Clanton, AL, 2015-2016.[z]

	Shoot length (cm)				
	2015				
Selection	30 Mar.	14 Apr.	20 Apr.	Sign.[y]	
‘U0501-12’	0.8 b[x]	60.8 b	87.9 b	L***	
‘U0502-01’	4.8 a	63.0 b	89.2 b	L***	
‘U0502-10’	4.2 a	71.3 a	99.8 a	L***	
	2016				
	30 Mar.	8 Apr.	15 Apr.	25 Apr.	Sign.
‘U0501-12’	0.0 c	15.0 c	34.4 b	77.6 b	Q***
‘U0502-01’	3.9 b	19.6 b	36.9 b	79.6 b	Q***
‘U0502-10’	7.5 a	28.8 a	51.3 a	95.5 a	Q***

[z] The selection by date interaction was significant at α = 0.05 in both years.

[y] Significant (Sign.) linear (L) or quadratic (Q) trends using orthogonal polynomials at α = 0.001 (***).

[x] Least squares means comparisons among selections (lower case in columns) using the Shaffer-simulated method at α = 0.05.

Table 2.3. Open flower progression of Pierce's disease resistant 87.5% *Vitis vinifera* selections grown at the Chilton Research and Extension Center, Clanton, AL, 2015-2016.[z]

	Percent open flowers[y]				
	2015				
Selection	1 May	6 May	11 May	Sign.[x]	Spur location
'U0501-12'	0 b[w]	80 a	100 b	Q***	Basal 70 a[v]
'U0502-01'	20 a	60 b	100 b	L***	Distal 60 b
'U0502-10'	0 b	60 b	80 b	Q***	
	2016				
	2 May	10 May	12 May	Sign.[y]	
'U0501-12'	0 ns	60 b	90 b	Q***	
'U0502-01'	0	90 a	100 a	Q***	
'U0502-10'	0	90 a	90 b	Q***	

[z] The selection by date and spur location main effect were significant in 2015 and the selection by date interaction was significant in 2016 at α = 0.05

[y] Open flowers scale: 0= 0% open flowers; 5= 1-5% open flowers; 10= 6-10% open flowers; 15= 11-15 % open flowers; 20= 16-20 % open flowers; 25= 21-25 % open flowers; 30= 26-30 % open flowers; 35= 31-35 % open flowers; 40= 36-40 % open flowers; 45= 41-45 % open flowers; 50 = 46-50 % open flowers; 55 = 51-55 % open flowers; 60 =56-60 % open flowers; 65= 61-65 % open flowers; 70 = 66-70 % open flowers; 75= 71-75 % open flowers; 80 = 76-80 % open flowers; 85= 81-85 % open flowers; 90= 86-90 % open flowers; 95= 91-95 % open flowers; 100= 96-100 % open flowers.

[x] Significant (Sign.) linear (L) or quadratic (Q) trends using orthogonal polynomials at α = 0.001 (***).

[w] Data presented are medians. Comparisons among selections and spur locations (lower case in columns) using estimate statements at α = 0.05. ns= not significant.

[v] Difference in spur ID using main effect F-test at α = 0.05.

Table 2.4. Veraison progression of Pierce's disease resistant 87.5% *Vitis vinifera* selections grown at the Chilton Research and Extension Center, Clanton, AL, 2015.[z]

	Percent berries turning color[y]					
	Selection					
	'U0501-12'		'U0502-01'		'U0502-10'	
	Spur location		Spur location		Spur location	
Date	Basal	Distal	Basal	Distal	Basal	Distal
3 July	0 nsB[x]	0 B	0 nsB	0 B	47 bA	56 aA
12 July	0 nsB	0 B	0 nsA	0 B	90 nsA	93 A
23 July	0 nsB	1 B	1 nsB	2 B	100 nsA	100 A
8 Aug.	0 nsB	1 C	11 bB	16 aB	100 nsA	100 A
14 Aug.	2 nsC	3 C	23 bB	36 aB	100 nsA	100 A
21 Aug.	3 nsC	5 C	30 bB	43 aB	100 nsA	100 A
7 Sept.	53 nsC	60 C	64 bB	75 aB	100 nsA	100 A
16 Sept.	77 nsB	84 B	79 bB	87 aB	100 nsA	100 A
23 Sept.	88 nsB	91 B	89 bB	93 aB	100 nsA	100 A
29 Sept.	96 nsNS	96 NS	96 ns	96	100 ns	100
8 Oct.	100 nsNS	100 NS	100 ns	100	100 ns	100
Sign.[w]	Q***	Q***	Q***	Q***	Q***	Q***

[z] There was a selection by spur location by date interaction at α = 0.05.

[y] Berry color (%): 0-100% scale.

[x] Least squares means comparisons between spur locations (lower case in rows) and among selections (upper case in rows) using the Shaffer-simulated method at α = 0.05. ns, NS = not significant.

[w] Significant (Sign.) quadratic (Q) trends using orthogonal polynomials at α = 0.001 (***).

Table 2.5. Veraison progression of Pierce's disease resistant 87.5% *Vitis vinifera* selections grown at the Chilton Research and Extension Center, Clanton, AL, 2016.[z]

	Percent berries turning color[y]		
	Selection		
Date	'U0501-12'	'U0502-01'	'U0502-10'
1 July	0.0 b[y]	0.0 b	19.6 a
5 July	0.0 b	0.0 b	34.2 a
12 July	0.0 b	0.0 b	70.5 a
25 July	0.0 b	1.5 b	98.8 a
2 Aug.	0.0 c	11.7 b	100.0 a
6 Aug.	0.0 c	22.4 b	100.0 a
17 Aug.	0.8 c	42.8 b	100.0 a
29 Aug.	4.5 c	64.4 b	100.0 a
31 Aug.	12.5 c	78.8 b	100.0 a
5 Sept.	24.7 c	93.8 b	100.0 a
20 Sept.	60.8 b	100.0 a	100.0 a
12 Oct.	100.0 ns	100.0	100.0
Sign.[x]	Q***	C***	Q***
Spur location	Basal	Distal	
	47.5 b[w]	49.3 a	

[z] Only the selection by date interaction and the spur location main effect were significant at α = 0.05.

[y] Berry color (%): 0-100% scale.

[x] Least squares means comparisons among selections (lower case in rows) using the Shaffer-simulated method at α = 0.05. ns = not significant.

[x] Significant (Sign.) quadratic (Q) or cubic (C) trends using orthogonal polynomials at α = 0.001 (***).

[w] Least squares means comparison between spur locations using main effect F-test at α = 0.05.

Table 2.6. Dormant pruning weights of Pierce's disease resistant 87.5% *Vitis vinifera* selections grown at the Chilton Research and Extension Center, Clanton, AL, 2015-2016.[z]

	Dormant pruning weight (kg)/vine	
Selection	2015	2016
'U0501-12'	2.0 aB[y]	2.9 aA
'U0502-01'	2.0 aB	2.4 bA
'U0502-10'	1.8 bB	2.5 bA

[z] The year by selection interaction was significant at α = 0.05.

[y] Least squares means comparison among selections (lower case in columns) and between years (upper case in rows) using the Shaffer-simulated method α = 0.05.

Table 2.7. Trunk cross-sectional-area (TCSA) of Pierce's disease resistant 87.5% *Vitis vinifera* selections grown at the Chilton Research and Extension Center, Clanton, AL, 2015-2016.

	TCSA (cm^2)	
Selection	Nov. 2015	Oct. 2016
'U0501-12'	150.5 b[z]	168.5 b
'U0502-01'	187.3 a	226.2 a
'U0502-10'	183.3 a	209.4 a

[z] Least squares means comparison among selections (lower case in columns) using the Shaffer-simulated method α = 0.05.

Table 2.8. Foliar characteristics of Pierce's disease resistant 87.5% *Vitis vinifera* selections grown at the Chilton Research and Extension Center, Clanton, AL, 2015-2016.

Selection	Chlorophyll content[z]	Leaf area (cm^2)	Pn[y]
'U0501-12'	31.1 ns[x]	65.8 b	6.6 ns
'U0502-01'	31.9	80.2 a	5.7
'U0502-10'	30.7	54.1 c	7.5

[z] SPAD-502 meter value.

[y] Pn: Photosynthetis rate

[x] Least squares means comparison among selections (lower case in columns) using the Shaffer-simulated method α = 0.05. ns = not significant.

Table 2.9. Total yield and growth to yield relationship of Pierce's disease resistant 87.5% *Vitis vinifera* selections grown at the Chilton Research and Extension Center, Clanton, AL, 2015-2016.

	2015				
Selection	Clusters (no.)/ vine	Yield (kg)/ vine	Cluster weight (g)	Growth-yield relationship[z]	Ravaz index[y]
'U0501-12'	45 a[x]	8.7 b	240.6 c	4.4 b	3.1 b
'U0502-01'	48 a	10.7 a	298.0 b	5.6 a	4.5 a
'U0502-10'	27 b	10.9 a	467.4 a	6.2 a	4.5 a

	2016			
	Clusters (no.)/ vine	Yield (kg)/ vine	Cluster weight (g)	Growth-yield relationship[w]
'U0501-12'	61 a	8.3 b	189.2 c	3.0 c
'U0502-01'	50 b	10.1 b	243.6 b	4.3 b
'U0502-10'	28 c	13.4 a	567.7 a	5.5 a

[z] Growth-yield relationship: 2015 yield/vine divided by 2015 dormant pruning weight/vine.

[y] Ravaz index: 2015 yield/vine divided by 2016 dormant pruning weight/vine.

[x] Least squares means comparison among selections (lower case in columns) using the Shaffer-simulated method $\alpha = 0.05$.

[w] Growth-yield relationship: 2016 yield/vine divided by 2016 dormant pruning weight/vine.

Table 2.10. Fruit quality of Pierce’s disease resistant 87.5% *Vitis vinifera* selections grown at CREC, Clanton, AL, 2015-2016.

	2015					
Selection	Berry weight (g)	pH	TA[z] (g/L)	SSC (° Brix)	Brix:TA ratio	$\text{pH}^2\times$(Brix)
‘U0501-12’	1.3 c[x]	3.24 b	16.2 a	21.1 a	15.7 b	224.5 a
‘U0502-01’	2.9 a	3.41 a	5.4 b	19.8 b	37.4 a	231.0 a
‘U0502-10’	1.8 b	3.01 c	13.9 a	17.0 c	16.8 b	155.7 b

	2016					
	Berry weight (g)	pH	TA (g/L)	SSC (° Brix)	Brix:TA Ratio	$\text{pH}^2\times$(Brix)
‘U0501-12’	1.4 c	3.03 c	6.2 a	23.1 a	38.1 a	213.0 ns
‘U0502-01’	2.7 a	3.25 b	5.2 b	20.1 b	39.3 a	212.9
‘U0502-10’	2.0 b	3.34 a	6.1 a	18.6 c	30.4 b	207.0

[z] TA: Titratable acidity.

[x] Least squares means comparison among selections (lower case in columns) using the Shaffer-simulated method $\alpha = 0.05$. ns= not significant.

Figure 2.1. Pierce’s disease resistant 87.5% *V. vinifera* selection ‘U0501-12’ grown at Chilton Research Extension Center, Clanton, AL, 2016.

Figure 2.2. Pierce’s disease resistant 87.5% *V. vinifera* selection ‘U0502-01’ grown at Chilton Research Extension Center, Clanton, AL, 2015.

Figure 2.3. Pierce's disease resistant 87.5% *V. vinifera* selection 'U0502-10' grown at Chilton Research Extension Center, Clanton, AL, 2016.

CHAPTER THREE

Assessment of Rootstocks for Sustainable Hybrid Bunch Grape Production in Alabama

Abstract

Currently, production of bunch grape species in the Southeastern U.S. is severely limited by Pierce's Disease (PD), a disease of grapes caused by the endemic, xylem-limited bacterium, *Xylella fastidiosa*. Because of PD pressure in the Southeast region, and particularly Alabama, rootstock availability for bunch grape growers is severely limited. The objectives of this experiment were to evaluate the effects of selected rootstocks on the viticultural performance, phenological development, and vegetative traits of two hybrid bunch grape cultivars, 'Chardonel' and PD tolerant 'Norton'. The experimental vineyard was established in spring of 2014 and consisted of six rootstock-scion combinations: 'Chardonel' own-rooted (OWR), 'Chardonel' grafted on '1103P' rootstock, 'Norton' OWR, and 'Norton' grafted on '1103P', '5BB', and '5C' rootstocks. Results indicate that during the first year of crop production, 'Chardonel' grafted on '1103P' yielded 8.3 kg/vine and was the best performing combination in terms of cropping potential. Fruit soluble solid content (SSC) was highest in 'Chardonel' OWR and 'Chardonel' grafted on '1103P', with SSC of 20.2% and 21.3% respectively, while all 'Norton' treatments had SSC of 18.9%. Rootstock suckering was notable for 'Chardonel' grafted on '1103P' where vines produced an average of 8 rootstock suckers per vine throughout the growing season, while no other combination exceed one rootstock sucker per vine throughout the year. Trunk cross-sectional-area (TCSA) indicated the treatments with the highest vigor at the end of the 2016 growing season were 'Chardonel' grafted on '1103P' and 'Chardonel' OWR with TCSA of 72.3 and 44.2 cm^2 respectively, while 'Norton' grafted on '5BB' resulted in the

lowest vigor of only 19.0 cm^2 TCSA. While the 2016 growing season gave the first indications of the impact of rootstock selection on vine productivity, to ascertain the long-term effect of rootstocks on vineyard longevity, productivity, and vigor, further evaluations must be conducted in the expanding viticultural region of Alabama.

Introduction

Through the combination of scion and rootstock, viticulturists are armed with a unique tool to ensure crop production in grapes (Pongrácz, 1983). While scions are often selected for fruit quality or disease resistance, rootstocks are selected to overcome diverse environmental constraints including pests, diseases, and poor soil conditions (Galet, 1998). Alternatively, rootstocks may be selected to manipulate the timing of vine development, timing of fruit maturation, or vegetative growth characteristics of the scion (Pongrácz, 1983; Wolpert, 2005). Phenological development of grape roots begins following bud burst on shoots, rather than prior to shoot growth (Coombe and Dry, 1992). Rootstock also plays a role in the final grape must's yeast assimilable nitrogen (YAN) content that can alter fermentation, affecting not only the vine but the ultimate product of *V. vinifera* grapes, the wine (Stockert and Smart, 2008). The onset of phylloxera (*Phylloxera vitifoliae* Fitch) initiated the utilization of North American *Vitis* species for the breeding of rootstocks capable of high performance in the presence of the pest (Pongrácz, 1983; Rombough, 2002; Jackson, 2008). Rootstocks commonly used include '1103 Paulsen' ('1103P'), '5BB Kober' ('5BB'), and '5C Teleki' ('5C') (Pongrácz, 1983). Phylloxera resistant species include *V. berlandieri*, *V. riparia,* and *V. rupestris* (Pongrácz, 1983). Species resistant to root-knot nematodes (*Meloidogyne* spp.) include *V. champini*, *V. cinerea,* and *V. longii* (Mullins et al., 1992).

‘1103P’ is a rootstock bred from a *V. berlandieri ×rupestris* cross that imparts high to moderate vigor, with moderate tolerance of waterlogged soils (Pongrácz, 1983). ‘1103P’ is tolerant of drought, salinity, and alkaline soils. In a rootstock and training trial of ‘Sunbelt’ grapevine, derived from open-pollinated ‘Concord’ Ravaz index was higher in ‘Sunbelt’ on its own roots and trained to Geneva Double Curtain (Morris et al., 2007). ‘Sunbelt’ grafted on ‘1103P’ had lower fruit pH when trained on a bilateral cordon and had greater pruning weight. Aerial root formation of ‘Petit Verdot’ grafted on ‘1103P’ was greater when compared to own-rooted plants following a major April freeze event in Oklahoma (Stafne, 2007). However, no difference was seen in any other cultivar when comparing own-rooted and ‘1103P’ grafted vines. In ‘Petit Verdot,’ 50% budbreak occurred 5 days earlier on its own roots than on ‘1103P’ grafted ones, and for own rooted vines, budbreak occurred 15 days prior to the major freeze events.

‘5BB’ is a rootstock resulting from a *V. berlandieri ×riparia* cross that gives scions moderate to high vigor (Galet, 1998, Pongrácz, 1983). This rootstock is not tolerant of waterlogged soils, drought, or excessive soil acidity. ‘5BB’ is tolerant of lime in soils, is moderately sensitive to salt, and has been observed to have reduced fruit set in highly fertile soils. In an Arkansas rootstock evaluation with ‘Chardonel’ scions, ‘5BB’ yielded the largest berry weight (Main et al., 2002). In the Fayetteville, AR planting, ‘5BB’ rootstocks had a 40% increase in yield, though ‘5BB’ also resulted in higher fruit pH and potassium concentrations that may be considered flaws in fruit quality for wine production. In a Missouri rootstock study using ‘Norton’ as the scion, ‘5BB’ yielded more fruit in larger clusters than own-rooted ‘Norton’ (Harris, 2013). Petiole phosphorous levels were below the acceptable range for both own-rooted and ‘5BB’, while calcium content was inadequate for ‘1103P’. ‘Chardonnay’ on ‘5BB’ produced fruit with the highest juice potassium and pH, while ‘1103P’ and ‘5C’ produced juice with the lowest potassium and pH level (Boselli et al., 1992). Schreiner (2003) found that ‘5BB’ imparted the highest vigor to scion ‘Pinot noir’ clone FPMS 2A, also noting increased levels of arbuscular mycorrhizal fungi colonization for ‘5BB’ grafted vines.

‘5C’ is a rootstock with *V. berlandieri ×riparia* lineage that enables moderate scion vigor (Pongrácz, 1983). ‘5C’ is not tolerant of waterlogged soils, drought, or acidic soils, but it is tolerant of lime in the soil and considered good for advancing vine maturity.

Goodman et al. (1993) reported ‘5C’ as crown gall susceptible and ‘5BB’ as resistant to crown gall. In a 6-year inoculation study, ‘5C’ had 13% survival rate (Süle and Burr, 1998). Roh et al. (2003) evaluated ‘1103P’, ‘5BB’, and ‘5C’ rootstocks and found them moderately susceptible to crown gall.

While flooding should be avoided by site selection, unpredictable conditions may bring periodic flooding in field conditions. Flooding intolerance can be confused with susceptibility to *Phytophthora cinnamomi* Rands, especially in field evaluations. Growth of flooded ‘Seyval Blanc’ vines grafted on ‘3309C’ rootstock continued at the same growth rate as unflooded vines over a 9-day period (Striegler et al., 1993). ‘St. George,’ ‘Riparia gloire,’ and ‘3309C’ rootstocks had greater flood tolerance than ‘5BB’, ‘Cynthiana’, and un-grafted ‘Seyval Blanc’. Root regeneration was not observed in ‘Cynthiana’ during the experiment. ‘1103P’ rootstock was highly susceptible to *P. cinnamomi* (Marais, 1979). In a comparison of 27 rootstocks, ‘1103P’ and ‘5C’ were drought tolerant, while ‘5BB’ was less tolerant of extended periods of drought (Carbonneau, 1985).

Soil acidity can negatively affect grapevines. Himelrick (1991) reported reduced root dry weigh and volume for ‘5BB’ rootstocks grown at low-soil pH (4.8). Soil pH below 5.5 can lead to Al and Mn toxicities that can adversely affect root growth and development (Foy et al., 1978; Taylor, 1988).

Pearson and Goheen (1988) found that PD resistance or tolerance is present in rootstocks with *V. aestivalis, V. berlandieri*, *V. champini*, or *V. rupestris* parentage. ‘Dog Ridge’ has very high PD resistance (Loomis, 1965; Pearson and Goheen, 1988). ‘Dog Ridge’ performed well under high PD pressure over an extended period of time in Florida (Mortensen 1972). ‘3309C’ vines had the most severe PD symptoms in a Tallahassee, FL study of un-grafted rootstocks grown under high PD pressure; vines were rated on a 0-5 scale where 0= no symptoms and 5= over 75% of leaves with marginal necrosis or vines were dead. ‘3309C’ vines received a score of 4.2 while ‘5BB’, ‘5C’, and ‘Ramsey’ scored 1.6, 1.9, and 1.0 respectively (Lu et al., 2003). ‘5BB’ had 70% survival after 3 years of cultivation in the field when compared to 90% survival of ‘5C’, 10% survival of ‘Freedom’, and 100% survival of ‘Ramsey’ rootstock.

Vine physiology and foliar characteristics may also be impacted by rootstock. ‘Riesling’ grapes grafted on ‘5BB’ had higher maximum photosynthesis rates compared to own-rooted vines (Düring, 1994). Similarly, ‘Muller Thurgau’ had higher photosynthesis rates when grafted on ‘5BB’ when compared to vines grafted on ‘5C’ (Candolfi-Vasconcelos et al., 1997). Chlorophyll content was highest in vines grafted on ‘5BB’ (Keller et al., 2001).

Vine growth, vigor, and yield may be affected by rootstock choice. Loomis (1952) found that rootstocks could improve yield, with yield increases noted for ‘Dog Ridge’ and other rootstocks. Yield increases were seen in all grafted vines by Hedberg (1980). For grafted ‘Gruner Veltliner,’ wood production was greater for ‘5BB’ and ‘5C’ when compared to own-rooted vines (Wunderer et al., 1999). ‘Gruner Veltliner’ grew more rapidly and fruit ripening occurred earlier when grafted on ‘1103P’ rootstock when compared to ‘5C’ rootstock (Fardossi et al., 1995).

‘Italia’ was higher yielding when grafted on ‘1103P’ rootstock when compared to own-rooted (Ezzahouani and Larry, 1997). Own-rooted, unirrigated ‘Shiraz’ had greater yields than ‘Shiraz’ grafted on ‘1103P’ vines (McCarthy et al., 1997).

McCraw et al. (2005) found no differences among own-rooted ‘Chardonnay’ when compared to ‘Chardonnay’ grafted to ‘1103P’ or ‘5BB’ vines in fruit quality, harvest date, or yield characteristics. ‘Chardonel’ vines grafted to ‘5BB’ yielded 40% higher than own rooted vines (Main et al, 2002). ‘Chardonnay’ vines had reduced size and vigor when grafted on ‘5BB’ and ‘1103P’ (Ferroni and Scalabrelli, 1993). Reynold and Wardle (2001), comparing the rootstocks ‘5BB’, ‘5C’, and two other rootstocks with nine scions, found no impact of rootstock on yield per vine, clusters per vine, cluster weight, or berry weight.

In double guyot pruned ‘Sauvignon blanc’ vines with eight buds per cane and two yielding canes per vine grafted on ‘5BB’, ‘SO4’, ‘Börner’, and ‘41B/72’, vines grafted on ‘41B/72’ were the highest yielding (Pulko et al., 2012). However, ‘5BB’ fruit had higher total soluble solids content in both years and the highest average soluble solids over the two-year study.

Dodson (2014) found differences in yields and pruning weights of vines grafted to the rootstocks, ‘1103P’, ‘5BB’, and ‘5C’. In a Sacramento County CA ‘Chardonnay’ vineyard receiving 419 mm of annual rainfall, vines grafted on ‘1103P’ were highly productive, while ‘5BB’ and ‘5C’ grafted vines were moderately productive. Contrastingly, in a Sacramento County CA ‘Cabernet Sauvignon’ vineyard with 490 mm of rainfall, ‘5BB’ was the highest yielding rootstock followed by ‘5C’, with ‘1103P’ the lowest yielding vine. Yield was lowest for ‘5BB’ and ‘1103P’ grafted on ‘Zinfandel’ at an Amador County CA vineyard despite both rootstocks having the highest pruning weights when compared to ‘5BB’ grafted vines.

Use of native grasses as a cover crop resulted in the lowest pruning weights over a three-year study of ‘Merlot’ grafted on ‘5BB’ in a drip-irrigated Sacramento County CA vineyard (Ingels et al., 2001). Pruning weights were always significantly lower than those of the disked control without negatively affecting fruit yield, brix, or pH. Native grasses also resulted in the lowest petiole concentrations of nitrate-N and the lowest leaf blade total N.

‘Chardonel’ is a late ripening white wine variety developed by the New York State Experiment Station (Reisch et al., 1990). It has moderately vigorous vines that may be grown on its own roots in phylloxera infested soils. A moderately cold hardy variety (-10 to -15 °F), ‘Chardonel’ has perfect, self-fertile flowers and is the result of a ‘Seyval’ ×‘Chardonnay’ cross made in 1953. With a medium-late bloom time following a late bud break, cluster thinning is seldom necessary. ‘Chardonel’ is considered moderately susceptible to downy mildew, botrytis bunch rot, crown gall, black rot, and anthracnose. It is however highly susceptible to phomopsis cane and leaf spot, and powdery mildew, but not susceptible to injury by sulfur applications.

‘Norton’, also known as ‘Cynthiana,’ is composed of *V. aestivalis*; it bears blue-black colored berries on small to medium clusters (Reisch et al., 1993). Cluster thinning is generally not needed for these late blooming and vigorous vines that require approximately 125 days from bloom to fruit maturity at harvest (Ambers and Ambers, 2004). ‘Norton’ is considered slightly susceptible to downy mildew, black rot, botrytis bunch rot, crown gall, phomopsis cane and leaf spot, powdery mildew, and anthracnose (Rink, 2005). ‘Norton’ is sensitive to injury from sulfur application and is moderately cold hardy (-10 to -15 °F), but requires 180 frost free days for fruit maturation. ‘Norton’ does not tolerate extended periods of wet soil. For a north-south oriented, high-bilateral cordon trained ‘Cynthiana’ vineyard, Main and Morris (2004) found that yield, cluster number, pruning weight, and Ravaz index were not affected by leaf removal, but wines were darker in color when made from vines that had leaves removed. In a particularly hot year, with maximum temperatures of 35 °C or greater during veraison, removal of leaves resulted in reduced pH and malic acid content of grapes.

Previous research in our lab (Hu, 2013) suggests that ungrafted ‘Cynthiana’ grown at the Sand Mountain Research Extension Center in Crossville, AL had a relatively low dormant pruning weight at 0.8 kg/vine. In the experiment, ‘Cynthiana’ berries had the highest sugar content (19.8 %) out of the 11 cultivars studied and yielded 5.7 kg/vine; ‘Cynthiana’ was harvested in late August 2011 and mid-August 2012. In 2011, ‘Cynthiana’ and ‘Champanel’ were the last cultivars to begin shoot development, with no leaves emerged by early April. Phenological development was slower for ‘Cynthiana’ than ‘Champanel’ in terms of bloom. Veraison stage was not recorded for ‘Cynthiana’ until July 25 in 2011 and July 13 in 2012. ‘Lake Emerald’ was the only selection with a later onset of veraison in the study with berries not beginning veraison until August in 2011 and July 27, 2012.

Grape rootstocks perform differently in different environments, under differing management practices, and when grafted with different scions; the only way to understand the vigor, yield, and environmental durability of a rootstock scion combination is to evaluate the combination within the region of interest. Growing in a similar environmental context is critical to interpreting a vine’s potential capacity for the Southeast region, yet very little is known about the growth of grape rootstocks in central Alabama amid PD, Armillaria root rot, nematodes, *Phytophthora* spp., and many other challenges common to the Southeastern environment.

To further the grape industry in Alabama and the Southeast, it is important to understand and evaluate rootstocks’ growth, vigor, and cropping potential as a sustainable management practice. Mortensen (1972) and Loomis (1952; 1965) conducted pioneering rootstock work in the

Deep South, yet critical work has not been conducted in Alabama to address the needs of the growing commercial viticulture industry. We conjecture that rootstock selection will have an effect on the growth, yield, and fruit quality of hybrid bunch grape cultivars in the Southeast and that, for the future of increased production of quality bunch grapes for Alabama's grape industry, it is necessary to evaluate commercially available options to develop recommendations for commercial production.

A 1999 Alabama Cooperative Extension System publication suggests 'Tampa', 'Lake Emerald', and 'Dog Ridge' as rootstock cultivar selections to be used across the state (Powell, et al., 1999). However, the high vigor of 'Dog Ridge' may lead to a challenging management situation. With the potential opportunity for expansion into new PD resistant *V. vinifera* type bunch grapes requiring grafting for field production, rootstock evaluation for their effects on yield, vigor, and overall plant health becomes even more pertinent to enhancing sustainable pest management via proper rootstock cultivar selection. The objective of this study was to ascertain the effect of the rootstock cultivars, '1103P', '5BB', and '5C' on growth and development of hybrid bunch grape cultivars, 'Chardonel' and 'Norton' in central Alabama.

Materials and Methods

To evaluate the effect of '1103P', '5BB', and '5C' grape rootstocks on the establishment, vigor, and initial fruit quality of two hybrid bunch grape cultivars, 'Chardonel' and 'Norton', an experimental vineyard was planted at the Chilton County Research and Extension Center (CREC) in 2014. One-year-old vines grafted on the selected rootstocks were planted into a Dothan fine-loam (kaolinitic, thermic Plinthic Kandiuudults) with soil pH adjusted to 6.2 prior to planting. The vines were planted in a completely randomized block design comprised of seven replications, with two experimental vines per rootstock-scion combination per replication. Drip irrigation was installed prior to planting. Nutrition was provided according to standard commercial practices (Poling, 2007). Pest management practices followed regional recommendations (Nita et al., 2016). Six treatments were applied that included two scion cultivars and three rootstock cultivars, namely own-rooted (OWR) ‘Chardonel’ and ‘Chardonel’ grafted on ‘1103P’ rootstock, OWR ‘Norton’ and ‘Norton’ grafted on ‘1103P’, ‘5BB’, and ‘5C’. Vines were trained to a single wire bilateral cordon system. All fruit were removed from vines in 2015. In 2016, fruit was thinned to one cluster per fruiting cane for an anticipated crop load of 30 clusters per vine.

Phenology

In 2016, vine shoot growth and fruit maturation were evaluated phenologically using the Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie (BBCH) scale (Lorenz et al., 1995). On each vine, two spurs per arm were designated for monitoring and data recording at the basal and distal regions of each cordon arm for a total of four spurs per vine.

Dormant bud development and early season shoot development were monitored in terms of leaf emergence. Phenological development was evaluated on a weekly basis from 30 Mar. to 24 Apr. Flowering was monitored in spring from 2 May to 17 May to determine the flowering progression. Floraison was deemed to have occurred when the mean value of vines’ inflorescences exceeded 50% flowers open.

Fruit development was monitored as berries progressed from fruit set to berry touch stages. Veraison and berry ripening was assessed throughout changes in berry color and fruit softening. To determine veraison progression, percent of berries changing color was visually rated for each vine as a percentage of berries per vine turned from an immature green to mature coloration. Ratings were conducted weekly starting on July 17, until 100 % of berries matured on August 2. Berry fruit brix was monitored periodically using a small sample size of 5-10 berries per block to determine the timing of crop maturity and harvest.

Vegetative Characteristics

Data was collected to determine the vine vigor and vegetative growth characteristics of each rootstock-scion combination. The traits measured to determine vine vigor included vine pruning weight, trunk cross sectional area (TCSA), and leaf area. Annual dormant pruning was conducted on 26 Feb. 2016. Pruning weights were determined for each individual vine using an Adam CPW plus-35 scale (Adam Equipment Inc., Danbury, CT). Vines were pruned to retain seven to eight spurs per cordon with two buds per spur for a total of fifteen spurs per vine and 30 buds per vine according to balanced pruning theory (Smart and Robinson, 1991). Trunk cross-sectional area was measured for each vine at 25 cm above the graft union using a digital caliper on 4 Feb. 2015, 12 Nov. 2015, and 12 Oct. 2016.

Leaf area was measured by collecting 10 recently matured leaves per vine for a total composite sample of 20 leaves per replication. Recently matured leaves were collected at random from the interior and exterior portions of the canopy during midsummer, at a minimum distance of 5 nodes below the terminal bud. Leaf area was measured using a Licor LI-3100 area meter (Licor Inc., Lincoln, NB, USA).

Leaf chlorophyll content was measured on 10 recently matured leaves per vine for a composite sample of 20 leaves per replication. Leaf chlorophyll content was measured using a SPAD-502 Plus chlorophyll meter (Konica Minolta Sensing, Inc., Osaka, Japan).

Foliar nutrient content was assessed by collecting a composite sample of 10 recently matured leaves per vine per block for a total sample of 20 leaves per rootstock-scion combination replication. Foliar tissue samples were stored at 4 ℃ until submitted to the Soil, Forage and Water Testing Laboratory at Auburn University (Auburn, AL) for analysis of elements by ICAP (Ca, Mg, K, P, Cu, Fe, Mn, Zn, B, Al, Na) and total nitrogen by combustion.

Throughout the growing season, rootstock suckering occurred. As needed, suckers were removed at the soil level and the number of individual rootstock suckers per vine was recorded.

Fruit Characteristics

During cordon establishment in 2015, all fruiting clusters were removed and counted. In 2016, crop load was adjusted by cluster removal to prevent over cropping and to reduce stress on the still developing vines. Vines were cluster-thinned to one cluster per fruiting shoot for a total number of 30 clusters retained per vine. Number of clusters removed per individual vine was counted.

Total yield per vine was measured at harvest for each experimental vine. Experimental vines were harvested by hand. The total number of clusters per vine was counted at harvest. For each individual vine, two subsamples of fruit were collected. Five clusters per vine were collected to determine cluster weight, and berry weight was determined based on a 50 berry subsample per vine using a digital scale (Adventurer Pro AV4101, Ohaus Corp., Pine Brook, NJ). Following harvest evaluations, grape berries were stored at 4 ℃ until fruit quality analysis was conducted. Two harvest metrics were calculated, growth-yield relationship (this year's yield/vine [kg] divided by this year's dormant pruning wood/vine [kg]) and Ravaz index (this year's yield/vine [kg] divided by next year's dormant pruning wood/vine [kg]).

Fruit quality analysis was conducted to evaluate fruit pH, titratable acidity (TA), and soluble solids content (SSC) using a 50-berry subsample per vine. Grapes were crushed with mortar and pestle, filtered through cheesecloth, and juice was stored in nonreactive glassware at 4 ℃ until further analysis. Berry pH was measured using an Accumet Basic AB 15 pH meter (Fisher Scientific, Hampton, NH). To measure TA, a one mL sample of grape juice was diluted to 40 mL of solution using deionized water. Titration was conducted to an endpoint of pH 8.2 using a 0.1 N NaOH titrant solution in a DL 15 Titrator (Mettler-Toledo LLC., Columbus, OH). Results were recorded as grams of tartaric acid equivalent per L of juice. SSC was measured at room temperature using extracted juice analyzed via a digital refractometer (Pal-1; Atago Co., Tokyo, Japan) and expressed as Brix (°B). Brix:TA ratio was calculated by dividing the SSC by the TA g/L (Goldammer, 2013). An additional metric for grape ripeness, pH^2*Brix, was also calculated (Coombe et al., 1980).

Results

Phenology

In 2016, ‘Chardonel’ grapevines had an early bud development and leaf emergence (Figure 3.1). On 30 Mar., both ‘Chardonel’ OWR and ‘Chardonel’ grafted on ‘1103P’ had at least one leaf emerged. Both ‘Chardonel’ treatments had greater than four leaves emerged on 8 Apr. ‘Norton’ treatments developed late in comparison to ‘Chardonel’ treatments.

Bloom initiated earliest for ‘Chardonel’ treatments, and on 2 May flowers located on distal spurs of ‘Chardonel’ grafted on ‘1103P’ reached 25% open flowers (Figure 3.2). By 10 May, ‘Chardonel’ treatments reached full bloom, and on 18 May, ‘Norton’ grapevines reached full bloom with at least 50% open flowers on distal and basal spurs of all ‘Norton’ treatments.

Veraison occurred earliest for ‘Chardonel’ and was completed by early July. ‘Norton’ vines, however, were late to progress through veraison, with first ripe berries recorded on 17 July (Table 3.3). The veraison progression occurred in a compact period, and by 25 July all ‘Norton’ rootstock combinations had over 50% of their berries changing color. On 2 Aug., all ‘Norton’ rootstock combinations had fully colored berries.

For the 2016 growing season, harvest of both ‘Chardonel’ treatments occurred on 2 Aug., and harvest of ‘Norton’ grafted on ‘1103P,’ ‘5BB,’ ‘5C,’ and OWR occurred on 1 Sept.

Vegetative Characteristics

There were no differences among scion-rootstock combinations in dormant pruning weight (Table 3.4) with the lowest values of 0.2 kg/vine for ‘Chardonel’ grafted on ‘1103P’, ‘Norton’ OWR, and ‘Norton’ grafted on ‘1103P’ and ‘5C’, and the highest value of 0.4 kg/vine for ‘Chardonel’ OWR. In future years, rootstock impact on vine vigor is anticipated to become more pronounced based on the dormant pruning weights as the vines establish and mature.

Rootstock effect on vine vigor became evident on 12 Nov. 2015 (Table 3.5). ‘Norton’ grafted on ‘5BB’ had the smallest overall TCSA of 10.5 cm^2 and ‘Chardonel’ grafted on ‘1103P’ had the largest (37.4 cm^2). All ‘Norton’ rootstock combinations had numerically lower TCSA than the two ‘Chardonel’ combinations. ‘Norton’ grafted on ‘1103P,’ produced the largest TCSA among ‘Norton’ treatments (18.5 cm^2) and was similar to OWR ‘Chardonel’ (20.1 cm^2). By the end of the 2016 season, TCSA had nearly doubled for ‘Chardonel’ vines grafted on ‘1103P’, expanding from 37.4 cm^2 to 72.3 cm^2. At all TCSA data collection dates, ‘Chardonel’ grafted on ‘1103P’ had the greatest numerical TCSA followed by ‘Chardonel’ OWR. In contrast, ‘Norton’ grafted on ‘5BB’ always had the smallest TCSA, and after three growing seasons had only reached 19.0 cm^2. ‘Norton’ OWR had the greatest TCSA of all ‘Norton’ treatments (31.5 cm^2), and was similar to ‘Norton’ grafted on ‘1103P’ (26.3 cm^2).

Rootstock suckering was only detected for rootstock-scion combinations with ‘1103P’ as a rootstock (Table 3.6). Rootstock suckering was most prevalent for ‘Chardonel’ grafted on ‘1103P’ which resulted in the highest total number of 8 rootstock suckers per vine removed throughout the growing season. Except for ‘Norton’ grafted on ‘1103P’, that required removal of one rootstock sucker per vine, no other scion-rootstock combination required sucker removal during the 2016 growing season.

No differences were found in terms of chlorophyll content of individual leaves, but leaf area measurements indicated ‘Chardonel’ grafted on ‘1103P’ and OWR vines had larger individual leaves than the ‘Norton’ rootstock combinations (Table 3.7).

Foliar nutrient content of ‘Chardonel’ grafted on ‘1103P’ and OWR were greater than ‘Norton’ grapevines for N, Ca, and Mg (Table 3.8). All treatments had sufficient N, P, Ca, and Mg; however, for potassium, all treatments with ‘Norton’ scions had slightly above the sufficiency level content of 0.5-1.0 % (Davenport and Horneck, 2011). ‘Norton’ vines grafted on ‘1103P’ and ‘5C’ had higher foliar potassium content, followed by ‘Norton’ grapes on ‘5BB’ and OWR which were intermediate, and ‘Chardonel’ grafted on ‘1103P’ and OWR had the lowest foliar potassium content. Phosphorus content for all rootstock-scion combinations was consistently between 0.17 and 0.22 %.

Foliar trace element content revealed no differences between rootstock scion combinations for Al, B, Cu, Mn, Na, or Zn (Table 3.9). However, Fe was highest for ‘Chardonel’ on ‘1103P’ and OWR, both with Fe content in excess of 100 ppm. ‘Norton’ combinations were lower in Fe concentration, ranging from 89.3 ppm for ‘Norton’ grapes grafted on ‘5C’ to 75.3

ppm for ‘Norton’ OWR. Foliar content of ‘Norton’ treatments for Fe and Zn were within sufficient range for grapevines, while B was slightly deficient based on the anticipated 30-100 ppm. Manganese was within sufficiency range for all treatments except ‘Chardonel’ grafted on ‘1103P’, which was slightly above the 30-100 ppm sufficiency range. Copper content was excessive for all treatments, likely due to contamination from fungicide application.

Fruit Characteristics

During the 2015 growing season, ‘Chardonel’ OWR had the greatest number of inflorescences resulting in the highest number of fruit clusters removed, while ‘Norton’ OWR vines had the least number (Table 3.10). ‘Chardonel’ OWR and ‘Chardonel’ on ‘1103P’ had 12 and 5 clusters removed per vine in contrast with the ‘Norton’ rootstock combinations, of which only ‘Norton’ vines grafted on ‘1103P’ and ‘5BB’ exceeded 2 clusters removed per vine.

As the vines were entering their first year of full production, crop load adjustment was applied to maximize vine health and longevity. Vines were cluster-thinned to maintain approximately one half of a commercial crop load. This was performed by hand thinning to one cluster per fruiting cane with anticipated cluster counts nearing 30 clusters per vine based on seven to eight spurs per cordon retained. ‘Chardonel’ grafted on ‘1103P’ was the most fruitful treatment, requiring 47 clusters to be removed per vine, followed by ‘Chardonel’ OWR (Table 3.11). ‘Norton’ combinations required less cluster thinning to achieve the targeted crop load.

'Norton' OWR grape, the least fruitful combination, had the fewest clusters and the smallest berries. 'Norton' OWR would have been within range of the targeted cluster number without thinning, this may be indicative of a reduced labor cost opportunity if favorable yields can be maintained without thinning.

After crop load adjustment to approximately one-half of the optimal commercial crop load, ‘Chardonel’ OWR vines yielded 7.7 kg/vine and ‘Chardonel’ grafted on ‘1103P’ produced 8.3 kg/vine, while ‘Norton’ yields were significantly lower (Table 3.12). ‘Norton’ OWR produced the lowest total yield of 0.8 kg/vine, while ‘Norton’ grafted on ‘5BB’ had the highest crop with 2.1 kg/vine. In the first commercial cropping year, the growth-yield relationship was highly variable, ranging from 5.2 to 51.1. It is anticipated that the Ravaz index calculated using the 2017 dormant pruning weights should provide a more accurate indication of crop productivity for the 2016 season.

Cluster weight for 'Chardonel' treatments was the largest, exceeding 300 g, while 'Norton' fruit clusters did not exceed 100 g regardless of rootstock. 'Norton' grafted on '5BB' and 'Chardonel' grafted on '1103P' had the highest cluster number per vine, both producing 34 clusters per vine. The number of clusters removed per vine during thinning indicates 'Chardonel' grape may require thinning as the vines mature. In contrast to 'Chardonel' grafted on '1103P' that required the greatest number of clusters thinned, 'Norton' on '1103P' required the second lowest thinning number of 17 clusters per vine.

Scion-rootstock combinations with 'Norton' scion had the smallest clusters and berries. 'Norton' individual berries ranged from 1.1 g for vines grafted on '1103P' and '5BB' to 0.9 g for 'Norton' OWR vines. ‘Chardonel’ berries were nearly twice the size of 'Norton' with 'Chardonel' OWR producing the largest overall berries of 2.1 g.

No differences were found between scion-rootstock combinations for berry juice pH (Table 3.13). Titratable acidity varied by scion alone, and was greater for 'Chardonel' and lower for 'Norton'. Juice SSC was numerically higher for 'Chardonel' grafted on '1103P' followed by

'Chardonel' OWR. No rootstock effect was found on SSC of 'Norton' vines. The Brix:TA ratio was greater for combinations with 'Norton' scions. While 'Norton' scions had lower SSC overall, their TA content was also lower, leading to TA ratios exceeding 32 in all 'Norton' combinations with a maximum ratio of 36.6 for 'Norton' grafted on '5C'. 'Chardonel' OWR had the lowest Brix:TA ratio of 28.9. Both 'Chardonel' combinations had numerically lower Brix:TA ratios compared to the 'Norton' combinations despite having greater SSC due to their greater TA content.

An additional metric for evaluating grape ripeness, $pH^2 \times Brix$, indicated no 'Norton' combination exceeded 210. Vines were potentially harvested before ideal ripening for a red grape that would lead to a value between 220 and 260 (Coombe et al., 1980). 'Chardonel' grafted on '1103P' had the greatest $pH^2 \times Brix$ at 232.5. Generally, a value exceeding 200 is considered acceptable for white grapes.

Discussion

‘Chardonel’ vines were phenologically the earliest developing and also most productive in the first year of cropping. ‘Norton’ has a proven record of consistent performance in the Southeastern U.S.’s hot and humid environment under relatively high pest and disease pressure. Further evaluation will characterize the long term sustainability of these rootstock selections for future bunch grape production in Alabama and the Southeastern U.S.

‘Chardonel’ grafted on ‘1103P’ produced the most prolific amount of rootstock suckering during the experimental period; this may be indicative of plant stress responses to factors within the root zone, or scion-rootstock interactions. ‘1103P’ was reported to have a tendency to produce rootstock suckers (Bonnet, 2016). ‘Norton’ grafted on ‘1103P’ was the only other combination to sucker, though considerably less than the ‘1103P’ grafted ‘Chardonel’ vines. The suckering of ‘1103P’ may create a management issue in the Southeast, future assessment will discover if this becomes a more prevalent occurrence or was a response to some environmental stress of the 2016 growing season.

The effect of rootstock on vine vigor is difficult to ascertain based on the first growing season data alone. Based on TCSA measurements, ‘1103P’ appears to have increased the relative vigor of ‘Chardonel’ compared to OWR vines. In ‘Norton’, vines grafted on ‘1103P’ and OWR were the most vigorous for all data collection points, while ‘Norton’ vines grafted on ‘5BB’ and ‘5C’ were less vigorous.

Although information is lacking on ‘Chardonel’ vine performance within the PD pressure area of Central Alabama, it is anticipated that traits from *V. rupestris* or *V. lincecummii* from the ‘Seyval blanc’ parent may impart some increased longevity. Three years’ growth and development in the Central Alabama’s high PD risk zone have provided the vines ample exposure to pests and inoculum. It is possible the vines could show symptoms of decline in the future, but at this initial stage, the vines were highly productive with excellent fruit quality at harvest.

‘Norton’ vines produced the lowest yields, but had crop thinning not been employed in 2016, they may have produced a larger crop. The fruit quality was promising in 2016, and with extended time period hanging on the vine, it might have been even higher quality in-terms of sugar accumulation. In future growing seasons, a difference in crop maturity amongst ‘Norton’ OWR and ‘Norton’ grafted on rootstocks ‘1103P’, ‘5BB’, and ‘5C’ is anticipated to be more pronounced.

Studies evaluating rootstock effects on viticultural performance of hybrid bunch grapes are lacking in the high PD pressure region of the Southeastern U.S. This research demonstrates preliminary results on yield potential, vegetative growth, and fruit quality of two commercially available bunch grape cultivars ‘Chardonel’ OWR and grafted on ‘1103P’ as well as ‘Norton’ OWR and grafted on ‘1103P’, ‘5BB’, and ‘5C’ rootstocks. Our results indicate ‘Chardonel’ grown in central Alabama ripens early in the growing season and has a high cropping potential for both OWR and ‘1103P’ grafted vines. However, a reason for concern is that ‘Chardonel’ bud break occurs relatively early, before the last threat of late spring frost has passed. ‘Norton’ grapevines, regardless of rootstock, start to develop considerably later than ‘Chardonel’, and their ripening is also late.

Understanding the vineyard longevity of these rootstock scion combinations in central Alabama will be important to growers in the Southeast seeking to manipulate vine vigor and productivity in an economically and environmentally sustainable manner.

Literature Cited

Ambers, R.K. and C.P. Ambers. 2004. Dr. Daniel Norborne Norton and the origin of the Norton grape. Amer. Wine Soc. J. 36: 77–87.

Bonnet, P. 2016. Pl@ntGrape, le catalogue des vignes cultivées en France. <http://plantgrape.plantnet-project.org/en/porte-greffe/1103%20Paulsen>.

Boselli, M., M. Fregoni, A. Vercesi, and B. Volpe. 1992. Variation in mineral composition and effects on the growth and yield of Chardonnay grapes on various rootstocks. Agricoltura Ricerca. 14:138-139.

Candolfi-Vasconcelos, M.C., M. Kummer, M. Keller, P. Basler, and W. Koblet. 1997. Nitrogen response of *Vitis vinifera* Muller-Thurgau grafted on 6 different rootstocks: canopy characteristics and leaf gas exchange. Proc. of the Fourth Int. Symp. on Cool Climate Viticult. & Enol. Rochester, New York, USA. 3:32-36.

Carbonneau, A. 1985. The early selection of grapevine rootstocks for resistance to drought conditions. Amer. J. Enol. Viticult. 36:195-198.

Coombe, B. G., R.J. Dundon, and A.W.S. Short. 1980. Indices of sugar—acidity as ripeness criteria for winegrapes. J. Sci. Food Agric. 31: 495–502.

Coombe, B.G. and P.R. Dry. 1992. Viticulture. Volume 2. Practices. Winetitles. Adelaide, Australia.

Davenport, J.R. and D.A. Horneck. 2011. Sampling guide for nutrient assessment of irrigated vineyards in the inland Pacific Northwest. Washington State University Extension. PNW 622.

Dodson, J. 2014. Grapevine rootstock-scion interactions and Influence on ripening periods and the initiation of senescence. Univ. California, Davis, PhD Diss.

Düring, H., 1994. Photosynthesis of ungrafted and grafted grapevines: effects of rootstock genotype and plant age. Am. J. of Enol. and Viticult. 45:297-299.

Ezzahouani, A. and L.E. Larry. 1997. Effect of rootstock on grapevine water status, productivity and grape quality of cultivar Italia. *Bulletin de l'OIV.*

Fardossi, A., W. Brandes, and C. Mayer. 1995. Influence of different rootstock cultivars on growth, leaf nutrient content and must quality of cultivar Gruner Veltliner. *Mitteilungen Klosterneuburg, Rebe und Wein, Obstbau und Fruchteverwertung*. 45:3-15.

Ferroni, G. and G. Scalabrelli. 1993. Effect of rootstock on vegetative activity and yield in grapevine. Int. Symp. on Viticult. and Enol. 37-42.

Foy, C.D., R.L. Chaney, and M.C. White. 1978. The physiology of metal toxicity in plants. Ann. Rev. Plant Physiol. 29:511-566.

Galet, P. 1998. Grape varieties and rootstock varieties. *Oenoplurimédia.* Chaintre, France.

Goodman, R.N., R. Grimm, and M. Frank. 1993. The influence of grape rootstocks on the crown gall infection process and on tumor development. Amer. J. of Enol. and Viticult. 44:22-26.

Goldammer, T. 2013. Grape grower's handbook. A complete guide to viticulture for wine production. Apex Publishers. Centreville, Virginia.

Harris, J.L. 2013. Effect of rootstock on vegetative growth, yield, and fruit composition of Norton grapevines. Univ. Missouri.Thesis.

Hedberg, P. 1980. Increased wine grape yields with rootstocks. Farmers' Newsletter 147: 22-24.

Himelrick, D.G., 1991. Growth and nutritional responses of nine grape cultivars to low soil pH. HortScience. 26:269-271.

Hu, Y. 2013. Feasibility of growing Pierce’s disease tolerant American and French-American hybrid bunch grape cultivars and advanced grape selections in Alabama. Auburn Univ. Thesis.

Ingels, C.A., K.M. Scow, D.A. Whisson, and R.E. Drenovsky. 2005. Effects of cover crops on grapevines, yield, juice composition, soil microbial ecology, and gopher activity. Amer. J. of Enol. and Viticult. 56:19-29.

Jackson, R.S. 2008. Wine science: Principles and applications. Academic Press. Burlington, Massachusetts.

Keller, M., M. Kummer, and M.C. Vasconcelos. 2001. Soil nitrogen utilisation for growth and gas exchange by grapevines in response to nitrogen supply and rootstock. Austral. J. Grape and Wine Res. 7:2-11.

Loomis, N.H., 1952. Effect of fourteen rootstocks on yield, vigor, and longevity of twelve varieties of grapes at Meridian, Mississippi. Proc. of the Amer. Soc. for Hort. Sci. 52:125-132.

Loomis, N.H. 1965. Further trials of grape rootstocks in Mississippi. Proc. Amer. Soc. Hort. Sci. 86:326-328.

Lorenz, D.H., K.W. Eichhorn, H. Bleiholder, R. Klose, U. Meier, and E. Weber.1995. Growth stages of the grapevine: phenological growth stages of the grapevine (*Vitis vinifera* L. ssp. *vinifera*)—codes and descriptions according to the extended BBCH scale. Austral. J. of Grape and Wine Res. 1:100-103.

Lu, J., Z. Ren, and P. Cousins. 2003. Field evaluation of grape rootstock response to natural infection by Pierce’s disease. Pierce’s Dis. Resistance Symp. Coronado, Calif. 19–22.

Main, G.L. and J.R. Morris. 2004. Leaf-removal effects on Cynthiana yield, juice composition, and wine composition. Amer. J. of Enol. and Viticult. 55:147-152.

Main, G., J. Morris, and K. Striegler. 2002. Rootstock effects on Chardonel productivity, fruit, and wine composition. Amer. J. of Enol. and Viticult. 53:37-40.

Marais, P.G., 1979. The situation regarding rootstocks resistant to *Phytophthora cinnamomi*. *Bulletin de l'OIV*. 52:357-376.

McCarthy, M.G., R.M. Cirami, and D.G. Furkaliev. 1997. Rootstock response of Shiraz (*Vitis vinifera*) grapevines to dry and drip-irrigated conditions. Austral. J. Grape and Wine Res. 3:95-98.

McCraw, B.D., W.G. McGlynn, and R.K. Striegler. 2005. Effect of rootstock on growth, yield and juice quality of *vinifera*, American and hybrid wine grapes in Oklahoma. Proc. Grapevine Rootstocks: Current Use, Res., and Application. 61-65.

Morris, J.R., G.L. Main, and R.K. Striegler. 2007. Rootstock and training system affect ‘Sunbelt' grape productivity and fruit composition. J. Amer. Pom. Soc. 61:71-77.

Mortensen, J.A. 1972. Dog Ridge, a superior grape rootstock for Florida. Proc. Fla. State Hort. Soc. 85:275-279.

Mullins, M.G., A. Bouquet, and L.E. Williams. 1992. Biology of the grapevine. Cambridge University Press. Cambridge, United Kingdom.

Nita, M., H. Burrack, D. Pfeiffer, W. Mitchem, D. Lockwood, B. Bellinger, P. Brannen, and P. Smith. 2016. 2016 Southeast regional bunch grape integrated management guide. Southern Region Small Fruit Consortium. <http://www.smallfruits.org/smallfruitsregguide/Guides/2016/BunchGrapeSprayGuide2016.pdf>.

Pearson, R.C. and A.C. Goheen. 1988. Compendium of grape diseases. APS Press. Saint Paul, MN.

Poling, E.B. (ed.) 2007. North Carolina Wine Grape Grower's Guide. NC Cooperative Extension Service. 535.

Pongrácz, D.P. 1983. Rootstocks for grapevines. David Philip Publishing. Cape Town, South Africa.

Powell, A., D. Himelrick, W. Dozier, and M.B. Musgrove. 1999. Fruit culture in Alabama: recommended rootstocks. ACES ANR-53-G. 1-2.

Pulko B., S. Vrsic, and J. Valdhuber. 2012. Influence of various rootstocks on the yield and grape composition of Sauvignon Blanc. Czech J. Food Sci. Vol. 30 p. 467-473

Reisch, B.I., R.N. Goodman, M.-H. Martens, and N.F. Weeden. 1993. The relationship between Norton and Cynthiana, red wine cultivars derived from *Vitis aestivalis*. Amer. J. Enol. Viticult. 44:441–444.

Reisch, B.I., R.M. Pool, W.B. Robinson, T. Henick-Kling, J.P. Watson, K.H. Kimball, M.H. Martens, G.S. Howell, D.P. Miller, C.E. Edson, and J.R. Morris. 1990. ‘Chardonel’ grape. HortScience 25:1666–1667.

Reynolds, A.G. and D.A. Wardle. 2001. Rootstocks impact vine performance and fruit composition of grapes in British Columbia. HortTechnology. 11:419-427.

Rink, J. 2005. The new eastern viticulture or Norton revisited. Amer. Wine Soc. J. 37:100–101.

Roh, J.H., H.K. Yun, K.S. Park, C.H. Lee, and S.B. Jeong. 2003. *In vivo* evaluation of resistance of grape varieties to crown gall disease. The Plant Pathol. J. 19:235-238.

Rombough, L. 2002. The grape grower: A guide to organic viticulture. Chelsea Green Publishing. White River Junction, VT.

Schreiner, R.P. 2003. Mycorrhizal colonization of grapevine rootstocks under field conditions. Amer. J. of Enol. and Viticult. 54:143-149.

Smart, R. and M. Robinson. 1991. Sunlight into wine: A handbook for winegrape canopy management. Winetitles. Adelaide, Australia.

Stafne, E.T. 2007. Analysis of the April 2007 freeze event in Oklahoma. 10 March 2016. <http://www.grapes.okstate.edu/PDFs/2007/AnalysisoftheApril2007FreezeEventinOklahoma.pdf>.

Stockert, C.M. and D.R. Smart. 2008. The physiological basis of rootstock control of grape fruit nitrogen composition. Proc. Nat. Viticult. Res. Conf. 78-79.

Striegler, R.K., G.S. Howell, and J.A. Flore. 1993. Influence of rootstock on the response of Seyval grapevines to flooding stress. Amer. J. of Enol. and Viticult. 44:313-319.

Süle, S. and T.J. Burr. 1998. The effect of resistance of rootstocks to crown gall (*Agrobacterium spp.*) on the susceptibility of scions in grape vine cultivars. Plant Pathol. 47:84-88.

Taylor, G.J. 1988. Plant-soil interactions at low pH. Commun. Soil Sci. Plant Anal. 19:775-1413.

Wolpert, J.A. 2005. Selection of rootstocks: Implications for quality. Proc. Grapevine Rootstocks: Current Use, Res., and Application. 25-33.

Wunderer, W., A. Fardossi. and J. Schmuckenschlager. 1999. *Einfluss von drei verschiedenen Unterlagen und zwei Erziehungssystemen auf die Leistung der Rebsorte Grüner Veltliner in Klosterneuburg. Mitteilungen Klosterneuburg Rebe und Wein, Obstbau und Früchteverwertung*. 49:57-64.

Table 3.1 Rootstock effects on early season leaf emergence progression of ‘Chardonel’ and ‘Norton’ grapes grown at Chilton Research Extension Center, Clanton, AL, 2016.[z]

		Leaf emergence number								
		Date							Spur location	
Scion cultivar	Rootstock cultivar	16 Mar.	25 Mar.	30 Mar.	8 Apr.	15 Apr.	25 Apr.	Sign.[y]	Basal	Distal
'Chardonel'	'1103P'	0 ns[x]	0 ns	1 a	4 a	6 a	9 a	Q***	3 aB[w]	4 aA
'Chardonel'	OWR	0	0	1 a	4 a	5 a	9 a	Q***	3 aB	4 aA
'Norton'	'1103P'	0	0	0 b	1 b	4 b	8 b	Q***	2 bNS	2 b
'Norton'	'5BB'	0	0	0 b	0 b	3 b	8 c	Q***	2 bNS	2 b
'Norton'	'5C'	0	0	0 b	1 b	4 b	8 bc	Q***	2 bNS	2 b
'Norton'	OWR	0	0	0 b	1 b	4 b	8 c	Q***	2 bNS	2 b
Spur location										
Basal		0 ns	0 ns	0 ns	2 b	4 b	8 b	Q***		
Distal		0	0	1	2 a	4 a	8 a	Q***		

[z] The treatment by date, spur location by date and treatment by spur location interactions were significant at α = 0.05.

[y] Significant (Sign.) quadratic (Q) trends using orthogonal polynomials at α = 0.001 (***).

[x] Least squares means comparisons (lower case in columns) using the Shaffer-Simulated method at α = 0.05. ns = not significant.

[w] Least squares means comparisons among treatments (lower case in columns) and between spur location (upper case in rows) using the Shaffer-Simulated method at α = 0.05. NS = not significant.

Table 3.2. Rootstock effects on open flower progression of ‘Chardonel’ and ‘Norton’ grapes grown at Chilton Research Extension Center, Clanton, AL, 2016.[z]

	Percent open flowers[y]											
	'Chardonel' '1103P'		'Chardonel' OWR		'Norton' '1103P'		'Norton' '5BB'		'Norton' '5C'		'Norton' OWR	
	Spur location		Spur location		Spur location		Spur location		Spur location		Spur location	
Date	Basal	Distal	Basal	Distal	Basal	Distal	Basal	Distal	Basal	Distal	Basal	Distal
2 May	5 bA[x]	25 aA	0 bB	5 B	0 nsB	0 C	0 nsB	0 C	0 nsB	0 C	0 nsB	0 C
10 May	90 nsA	90 A	90 nsA	90 A	0 nsB	0 B	0 nsB	0 B	0 nsB	0 B	0 nsB	0 B
12 May	90 nsA	95 A	90 nsA	90 A	0 nsB	0 B	0 nsB	0 B	0 nsB	0 B	0 nsB	0 B
18 May	100 nsA	100 A	100 nsA	100 A	60 bB	80 aBC	50 bB	75 aC	60 nsB	50 D	50 bB	90 ab
25 May	100 nsN	100 NS	100 ns	100	100 ns	100	100 ns	100	100 ns	100	100 ns	100
Sign.[w]	Q***	Q***	Q***	Q***	Q***	Q***	Q***	Q***	Q***	Q***	Q***	Q***

[z] There was a treatment by spur location by date interaction at α = 0.05.

[y] Open flowers scale: 0= 0% open flowers; 5= 1-5% open flowers; 10= 6-10% open flowers; 15= 11-15 % open flowers; 20= 16-20 % open flowers; 25= 21-25 % open flowers; 30= 26-30 % open flowers; 35= 31-35 % open flowers; 40= 36-40 % open flowers; 45= 41-45 % open flowers; 50 = 46-50 % open flowers; 55 = 51-55 % open flowers; 60 =56-60 % open flowers; 65= 61-65 % open flowers; 70 = 66-70 % open flowers; 75= 71-75 % open flowers; 80 = 76-80 % open flowers; 85= 81-85 % open flowers; 90= 86-90 % open flowers; 95= 91-95 % open flowers; 100= 96-100 % open flowers.

[x] Comparisons between spur locations (lower case in rows) and among cultivars (upper case in rows) using estimate statements at α = 0.05. ns,NS = not significant.

[w] Significant (Sign.) quadratic (Q) trends using orthogonal polynomials at α = 0.001 (***).

Table 3.3. Rootstock effects on veraison progression of ‘Norton’ grapes grown at Chilton Research Extension Center, Clanton, AL, 2016.[z]

		Percent berries turning color[y]			
Scion cultivar	Rootstock cultivar	17 July	25 July	2 Aug.	Sign.[x]
'Norton'	'1103P'	13.1 b[w]	59.9 bc	100.0 ns	L***
'Norton'	'5BB'	23.1 a	70.9 a	100.0	Q**
'Norton'	'5C'	19.6 ab	70.4 ab	100.0	Q***
'Norton'	OWR	14.9 ab	56.0 c	100.0	L***

[z] Only the treatment by date interaction was significant at $\alpha = 0.05$.

[y] Berry color (%): scale 0-100%.

[x] Significant (Sign.) linear (L) or quadratic (Q) trends using orthogonal polynomials at $\alpha = 0.01$ (**) or 0.001 (***).

[w] Least squares means comparisons (lower case in columns) using the Shaffer-Simulated method at $\alpha = 0.05$. ns = not significant.

Table 3.4. Rootstock effects on dormant pruning weight of ‘Chardonel’ and ‘Norton’ grapes grown at Chilton Research Extension Center, Clanton, AL, 2016.

Scion cultivar	Rootstock cultivar	Dormant pruning weight (kg)
‘Chardonel’	‘1103P’	0.2 ns[z]
	OWR	0.4
‘Norton’	‘1103P’	0.2
	‘5BB’	0.3
	‘5C’	0.2
	OWR	0.2

[z] Least squares means comparison within column (lower case) using the Shaffer-simulated method α = 0.05. ns = not significant.

Table 3.5. Rootstock effects on trunk-cross-sectional area (TCSA) of ‘Chardonel’ and ‘Norton’ grapes grown at Chilton Research Extension Center, Clanton, AL, 2015-2016.[z]

		TCSA (cm^2)	
Scion cultivar	Rootstock cultivar	Nov. 12, 2015	Oct. 12, 2016
‘Chardonel’	‘1103P’	37.4 aB	72.3 aA
	OWR	20.1 bB	44.2 bA
‘Norton’	‘1103P’	18.5 bB	26.3 cdA
	‘5BB’	10.5 cB	19.0 eA
	‘5C’	13.7 bcB	20.6 deA
	OWR	15.6 bcB	31.5 cA

[z] There was a treatment by date interaction at α = 0.05.

[y] Least squares means comparison within rows (upper case) and columns (lower case) using the Shaffer-simulated method α = 0.05. ns = not significant.

Table 3.6. Rootstock effects on suckering of ‘Chardonel’ and ‘Norton’ grapes grown at Chilton Research Extension Center, Clanton, AL, 2016.[z]

		Number of rootstock suckers removed				
Scion cultivar	Rootstock cultivar	25 Apr.	14 June	2 Aug.	12 Sept.	Total number of suckers 2016
‘Chardonel’	‘1103P’	3 a[y]	3 a	2 ns	1 ns	8 a
	OWR	0 b	0 b	0	0	0 b
‘Norton’	‘1103P’	0 ab	0 b	0	0	1 b
	‘5BB’	0 b	0 b	0	0	0 b
	‘5C’	0 b	0 b	0	0	0 b
	OWR	0 b	0 b	0	0	0 b

[z] Only the treatment by date interaction was significant at α = 0.05.

[y] Least squares means comparison within columns (lower case) using the Shaffer-simulated method α = 0.05. ns = not significant.

Table 3.7. Rootstock effects on foliar characteristics of ‘Chardonel’ and ‘Norton’ grapes grown at Chilton Research Extension Center, Clanton, AL, 2015-2016.

Scion cultivar	Rootstock cultivar	Chlorophyll content[z]	Leaf area (cm^2)
‘Chardonel’	‘1103P’	37.9 ns[y]	109.3 a
	OWR	38.9	102.5 a
‘Norton’	‘1103P’	39.6	71.8 b
	‘5BB’	39.6	70.9 b
	‘5C’	38.3	73.5 b
	OWR	39.6	73.3 b

[z] SPAD-502 meter value.

[y] Least squares means comparison within columns (lower case) using the Shaffer-simulated method $\alpha = 0.05$. ns = not significant.

Table 3.8. Rootstock effects on foliar nutrient content of 'Chardonel' and 'Norton' grown at Chilton Research Extension Center, Clanton, AL, 2016.

		N	P	K	Ca	Mg
Scion cultivar	Rootstock cultivar	%				
‘Chardonel’	‘1103P’	3.09 a[z]	0.17 c	0.66 c	2.72 a	0.48 a
	OWR	3.05 a	0.18 bc	0.68 c	2.52 a	0.43 a
‘Norton’	‘1103P’	2.53 b	0.22 a	1.32 a	1.33 c	0.32 b
	‘5BB’	2.50 b	0.19 abc	1.08 b	1.66 bc	0.28 b
	‘5C’	2.63 b	0.18 bc	1.32 a	1.88 b	0.27 b
	OWR	2.56 b	0.22 ab	1.07 b	1.69 bc	0.26 b

[z] Least squares means comparison within columns (lower case) using the Shaffer-simulated method α = 0.05.

Table 3.9. Rootstock effects on foliar trace element content of 'Chardonel' and 'Norton' grown at Chilton Research Extension Center, Clanton, AL, 2016.

		Al		B		Cu		Fe		Mn		Na		Zn	
Scion cultivar	Rootstock cultivar	ppm													
‘Chardonel’	‘1103P’	40.0	ns[z]	14.3	ns	178.5	ns	100.3	ab	103.0	ns	303.8	ns	37.0	ns
	OWR	43.8		15.3		172.8		110.3	a	89.8		240.0		35.8	
‘Norton’	‘1103P’	24.3		17.0		141.3		78.3	ab	62.0		329.8		34.5	
	‘5BB’	67.3		15.8		240.5		76.5	b	69.5		298.8		33.5	
	‘5C’	93.0		15.5		228.0		89.3	ab	63.5		354.3		40.8	
	OWR	38.3		18.0		153.0		75.3	b	83.5		272.3		39.8	

[z] Least squares means comparison within columns (lower case) using the Shaffer-simulated method α = 0.05. ns = not significant.

Table 3.10. Rootstock effects on number of clusters removed during vine establishment stage for ‘Chardonel’ and ‘Norton’ bunch grapes grown at Chilton Research Extension Center, Clanton, AL, 2015.

Scion cultivar	Rootstock cultivar	Number of clusters removed/vine
‘Chardonel’	‘1103P’	5 b[z]
	OWR	12 a
‘Norton’	‘1103P’	2 c
	‘5BB’	3 c
	‘5C’	2 c
	OWR	0 c

[z] Least squares means comparison within columns (lower case) using the Shaffer-simulated method $\alpha = 0.05$.

Table 3.11. Rootstock effects on number of clusters removed for ‘Chardonel’ and ‘Norton’ bunch grapes grown at Chilton Research Extension Center, Clanton, AL, 2016.

Scion cultivar	Rootstock cultivar	Number of clusters removed/vine
‘Chardonel’	‘1103P’	47 a[z]
	OWR	38 a
‘Norton’	‘1103P’	17 bc
	‘5BB’	23 b
	‘5C’	22 b
	OWR	12 c

[z] Least squares means comparison within columns (lower case) using the Shaffer-simulated method $\alpha = 0.05$.

Table 3.12. Effect of rootstocks on yield characteristics of ‘Chardonel’ and ‘Norton’ grapes grown at Chilton Research Extension Center, Clanton, AL, 2016.

Scion cultivar	Rootstock cultivar	Cluster (no.)/vine	Yield (kg)/vine	Cluster weight (g)	Berry weight (g)
‘Chardonel’	‘1103P’	34 a[z]	8.3 a	337.4 a	2.0 b
	OWR	27 ab	7.7 a	310.5 a	2.1 a
‘Norton’	‘1103P’	26 ab	1.3 b	81.1 b	1.1 c
	‘5BB’	34 a	2.1 b	96.0 b	1.1 c
	‘5C’	29 a	1.5 b	90.0 b	1.0 c
	OWR	20 b	0.8 b	68.7 b	0.9 d

[z] Least squares means comparison within columns (lower case) using the Shaffer-simulated method α = 0.05.

Table 3.13. Effect of rootstocks on fruit quality of ‘Chardonel’ and ‘Norton’ grapes grown at Chilton Research Extension Center, Clanton, AL, 2016.

Scion cultivar	Rootstock cultivar	pH	TA[z] (g/L)	SSC (˚Brix)	Brix:TA ratio	pH^2×(Brix)
‘Chardonel’	‘1103P’	3.29 ns[y]	7.0 a	21.3 a	31.0 ab	232.5 a
	OWR	3.21	7.4 a	20.2 a	28.9 b	209.5 b
‘Norton’	‘1103P’	3.29	5.6 b	18.9 b	34.4 ab	205.2 b
	‘5BB’	3.27	5.3 b	18.9 b	36.3 a	202.6 b
	‘5C’	3.31	5.3 b	18.9 b	36.6 a	207.3 b
	OWR	3.27	5.8 b	18.9 b	32.9 ab	203.4 b

[z] TA: Titratable acidity

[y] Least squares means comparison within columns (lower case) using the Shaffer-simulated method α = 0.05. ns = not significant.