IDENTIFYING OKLAHOMA GRAPE PRODUCERS' KNOWLEDGE OF PIERCE'S DISEASE

By

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IDENTIFYING OKLAHOMA GRAPE PRODUCERS'

KNOWLEDGE OF PIERCE'S DISEASE

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Abstract: In 2008, Pierce's disease was discovered in Oklahoma in a backyard garden. Limited research regarding Pierce's disease has been done to monitor the disease throughout the state. In 2008-2009 and in 2016-2017, two surveys were conducted based on suspect grape samples being submitted to the diagnostic lab for verification of the bacterium causing Pierce's disease, *Xylella fastidiosa.* With the disease being relatively new to the state, it is important to monitor knowledge of the disease among growers, as well as presence. This research was done using a questionnaire that was distributed via email link to n=63 producers. There was n=18 complete responses from 14 Oklahoma counties that could be analyzed. Although there were no new counties to report having Pierce's disease, analysis showed Oklahoma grape producers need more education regarding integrated pest management practices (IPM) and insect vector identification. It is important to note, there could be more vineyards that have the disease, but since producers' do not know how to identify symptoms, damage and vectors it is going undetected. The findings of this survey help determine Oklahoma grape producers' knowledge of Pierce's disease, ability to identify Pierce's disease, and ability to identify insect vectors for Pierce's disease. In addition, the purpose was to understand Oklahoma grape producers' knowledge and use of integrated pest management techniques.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Discovering Pierce's Disease

In 1880, a "mysterious disease" swept through the vines of California's wine country. In response, the California Legislature allowed the University of California to create a viticulture and enology program to provide instruction for grape producers and to assist with information for producers (Hakim, 2018).

With this program in place, Newton B. Pierce became the first formally trained grape plant pathologist in the America's to help aid with the "mysterious disease" issue. His detailed descriptions of the disease and its symptoms allowed successors to identify the grapevine disease as a strain from the bacterium, *Xylella fastidiosa* subsp. *fastidiosa* (Xf) 80 years later. To honor the plant pathologist, the disease was named Pierce's Disease (Hopkins & Purcell, 2002).

Xylella fastidiosa is a gram-negative bacterium that will survive and multiply in the xylem (water-conducting tissues) of plant cells (Martelli, 1993). Effectively, Xf restricts water movement throughout the plant by clogging xylem vessels. This results in visibly recognizable symptoms including leaf scorch (i.e., yellowing or reddening of the leaves within the first year of inoculation), along with a "matchstick" appearance (i.e. petioles left behind after leaves prematurely drop) and immature berry clusters) (Martelli, 1993; California Department of Food and Agriculture, 2020).

The pathogen is believed to have originated in Northern Mexico and the Southeastern United States (Wells et al., 1987). These areas have native, wild species that are more tolerant to the bacterium, so they do not always show symptoms, however, they still harbor the pathogen, and can transmit the bacterium to more susceptible plants (Mizell et al., 2015).

Symptom severity and the number of infected vines is greatly determined by geographical region and climate. *Xylella fastidiosa* has shown an intolerance to temperatures found in northern cool-cold states like New York or Washington. It has shown a preference, however, to subtropical and hot temperatures (Galvez et al., 2010).

Pierce's disease has been found in more than ten states in the U.S., including Alabama, Arkansas, California, Florida, Georgia, Mississippi, Missouri, North Carolina, Oklahoma, Texas, and Virginia (Blaauw et al., 2019). These states are in the southern part of the United States and usually have hot summers and mild winters. Pierce's disease can also be found in Central and South America. It has not, however, been commonly observed outside the Americas, except for some isolated cases in Europe (Boubals, 1989; Berisha et al., 1998). European grape (*Vitis vinifera* L.) varieties, are not resistant to the disease like some American and hybrid varieties (Mizell et al., 2015).

The key factors needed for transmission of Pierce's disease are different from region to region. These include environmental factors, such as geographic location and growing region, as well as insect vectors that transmit the disease (Galvez et al., 2010). Pierce's disease is almost exclusively transmitted vine to vine by xylem-feeding insects known as sharpshooters or leafhoppers (Mizell et al., 2015). The leafhopper species responsible for transmission of Xf vary among grape-growing regions. For example, California's key insect vector is the glassy winged sharpshooter, *Homalodisca vitripennis* (Germar), (GWSS), whereas Florida harbors the insect vector *Homalodisca insolita* (Walker) (Mizell et al., 2015).

Viticulture in the United States

The United States is home to several species of wild grapes, but commercial viticulture was first introduced to the United States by Spaniard settlement. At that time, grape cultivation was primarily used to produce communion wine. The Gold Rush caused the population of California to increase and wine gained more popularity outside the church (Borg, 2020). By the 1900s, California emerged as a global competitor in the wine industry, shipping around the world to Australia, Central America, England and Asia (Borg, 2018). This paved the way for the United States to become the 4th largest wine producer in the world and encouraged other states to participate in viticulture (Nelson et al., 2007).

The United States grape industry took a major hit when the 18th Amendment, went into effect with the passage of the Volstead Act of 1919 and the era of Prohibition began (Onion et al., 2010). The goal of Prohibition was to reduce rates of alcoholism and overall alcohol consumption. Prohibition resulted in the government eliminating the businesses that made, distributed and sold alcoholic beverages (Kerr, n.d.). Wine and grape producers took a dislike to the new law, believing wine to be "morally superior to the consumption of ordinary liquor" and perceived the production and consumption of wine as an "art" (Meers, 1967).

While Prohibition drastically decreased the sale of wine, the demand for fresh grapes skyrocketed with opportunistic, amateur wine makers and bootleggers now in business. Even though people involved in alcohol production for profit were breaking the law, they advocated for the repeal of the 18th Amendment and essentially saved the wine and grape industry (Borg, 2018). Although some states continued to enforce Prohibition as state law, the 21st Amendment in December of 1933 was the end of national prohibition (Borg, 2018).

Since the beginning of grape production in the United States, commercial viticulture has become more popular throughout the country. States like Texas, Arkansas and Florida, have taken an interest in the specialty crop. Increasing popularity and experience has made it possible for other states, like Oklahoma, to become a developing wine state as well.

Viticulture in Oklahoma

Oklahoma is home to vast vineyards of domesticated table and wine grape cultivation. This began in the late 1800s and continues to present day (Stafne, 2019). Even with Prohibition in place, Oklahoma produced more than an average of 1800 tons of grapes during the years of 1925-1928 (USDA, 1929). Excluding Arkansas, this was more than any state in the South-Central United States (Stafne, 2019).

Although it is not certain where or when non-native Oklahoma grape varieties were first cultivated in the state, they are thought to have come from the eastern United States. To help aid in the education gap between farmers and their crops, the USDA and Oklahoma A&M co-published *Grapes in Oklahoma* in 1926 (Stafne, n.d.). These publications shed new light on grape cultivation and provided insight for what commercial viticulture would eventually become in Oklahoma (Stafne, n.d.).

Compared to other states like California, the Oklahoma commercial grape industry is relatively small, with most vineyards two acres (0.81 hectares) or less (Rebek & Overall, 2017). Nevertheless, Oklahoma does have several native species such as *Vitis aestivalis* Michx, *V. mustangensis* Buckley, *V. riparia* Michx, and *V. rupestris* Scheele (Stafne, n.d.) Many of these native species have helped create high-quality hybrid varietals that grow well in the state. In 1907-1908, the state had an estimated 3,700-5,425 acres of grapes planted. This is about ten times the acreage of grapes planted in the state today (Stafne, n.d.).

The Oklahoma climate presents a challenge to producing high-quality grapes. Vines planted in Oklahoma must be able to adapt to cold and hot temperatures as well as have a strong fungal disease resistance. Soil is also a key factor for healthy vines, but it can be largely variable throughout the state (Stafne, n.d). It essential for Oklahoma producers to choose grape varieties, such as Chambourcin, which have vigor and can withstand these soil quality variations.

Grape growing in Oklahoma is a risky investment due to a history of unfavorable liquor laws, lack of education, and climate. Some popular non-native European grapes that can be grown in Oklahoma are Cabernet Sauvignon, Merlot, Shiraz, Chardonnay and Zinfandel (Stafne, 2019). These grapes varieties are not well suited for growing in Oklahoma, but viticulturalists plant them because they are popular around the world. Other varieties, like American and hybrid grapes can withstand Oklahoma's cold winters and hot summers and can be more resistant to diseases, such as Pierce's disease (Creasy et al., 2019).

Problem

There is no research regarding Oklahoma grape producers' knowledge of Pierce's disease. There is also no research regarding Oklahoma grape producers' ability to identify Pierce's disease as well as the insect vectors that transmit the disease. In addition, limited research has focused on Oklahoma grape producers' knowledge and use of integrated pest management techniques.

Purpose

The purpose of this study was to determine Oklahoma grape producers' knowledge of Pierce's disease, ability to identify Pierce's disease, and ability to identify insect vectors for Pierce's disease. In addition, the purpose is to understand Oklahoma grape producers' knowledge and use of integrated pest management techniques.

Research Objectives

The following research objectives guided this study:

1. Describe selected characteristics (size, geographic location, vineyard classification, and harvest value of production) of Oklahoma vineyards.
2. Identify Oklahoma grape producers' sources of information for pest management.
3. Determine Oklahoma grape producers' knowledge of Pierce's disease.

4. Determine Oklahoma grape producer's knowledge and use of pest management techniques.

Significance

For this study, there is a long-term educational benefit. The results will contribute to the future of Oklahoma viticulture by identifying education gaps so more information can be released on the subject in the future. This will help with the long-term health of producer's vines and could reduce costs associated with labor and loss of vines.

Scope of the Study

The scope of this study consisted of Oklahoma grape producers found on the Oklahoma Grape Industry Council (OGIC) email list. This list included 63 grape producers in Oklahoma. There could be more Oklahoma grape producers that were not on the OGIC email list.

Limitations

The following limitations were identified for this study:

1. The research data collection process was limited to only those with an email address and involved with the Oklahoma Grape Industry Council.

Assumptions

The following assumptions were made regarding this study:

1. Respondents would be honest about their perceptions of Pierce's disease.
2. Respondents were the most knowledgeable about Pierce's disease within each vineyard.
3. Respondents were interested in learning more about the Oklahoma grape industry and Pierce's disease.

CHAPTER II

REVIEW OF LITERATURE

Pierce's Disease

Pierce's disease is caused by the bacterium, *Xylella fastidiosa* subsp. *fastidiosa* (Xf) (Hopkins & Purcell, 2002). *Xylella fastidiosa* is a gram-negative bacterium that lives in the xylem (water-conducting) cells of plants and proceeds to multiply. This pathogen causes plant tissues to clog and symptoms such as leaf scorch, raisining of berry clusters and a "matchstick" appearance (Smith, 2019). The bacterium has a large host range with more than 100 plant hosts such as alfalfa, elm, maple, oak, sycamore, oleander, almond, citrus, and others (Smith, 2019). Pierce's disease, Alfalfa Dwarf and Almond Leaf Scorch are the same strain of Xf affecting grapes, alfalfa, and almond trees, respectively (Hopkins & Purcell, 2002).

There are several ways Pierce's disease can be transmitted to susceptible vines. The most common transmission of the bacterium is caused by xylem-feeding insect vectors (Hopkins & Purcell, 2002; Purcell, 1997). The main vectors for Pierce's disease includes several species of sharpshooters (Hemiptera: Cicadellidae). Spittlebugs (Hemiptera: Cercopidae) and cicadas (Hemiptera: Cicadidae) are vectors of different subspecies of Xf; however, they have other preferred hosts, so they do not cause Pierce's disease (Overall et al., 2015).

Vector species responsible for transmission of Pierce's disease varies from region to region. Successful transmission depends on only one infective individual to spread Xf to other plants. Once acquired, the bacterium can be inoculated into plants immediately when infective vectors begin feeding (Hopkins & Purcell, 2002; Purcell, 1997). Being able to identify key vector species within a vineyard is essential to preventing further transmission. As soon as the vectors are detected in the vineyard, insecticides registered for control of leafhoppers on grapes should be applied.

Hot and dry temperatures prolong the grape-growing season and will increase development of plant symptoms. This is because even with good soil moisture, moisture stress in the plant can be severe (Galvez et al., 2010). Increasing temperatures will lengthen the growing season, and possibly drought season, which could cause an increase in vectors giving them a longer and healthier breeding season (Galvez et al., 2010). Once plants are infected, they could possibly show symptoms of leaf necrosis, leaf scorching, leaf drop or die-back (Hopkins et al., 2002).

There are both susceptible and resistant grape cultivars. Many native grapes are resistant to Pierce's disease. There are also some grapes that are considered asymptomatic, meaning even if they carry the bacterium, they show no symptoms but act as hosts for vectors who transmit the disease. Even some infected plants can be asymptomatic (Gilchrist et al., 2006). Also, some infected plants can live up to five years before showing symptoms or dying, and vines two years or younger are particularly susceptible (Jackson, 2000). The conventional way to detect Pierce's disease in the vineyard is by visual detection, but presence of Xf within affected vines needs to be verified by a diagnostic lab (Smith, 2019). Once a plant becomes infected with the pathogen, it cannot be cured and all symptomatic vines should be removed from the vineyard to reduce further transmission (Overall & Rebek, 2017).

Vineyards have an expensive startup cost and, depending on the region, do not produce a harvest until the third to fifth growing season (Munroe, 2018). Therefore, removal of infected vines can result in substantial economic losses given the initial investment of money and labor required to grow a mature vine.

The threat of Pierce's disease is based on geographic location and severity and ranges from extreme to rare or non-existent (Hopkins & Purcell, 2002). The reason for the gradual spread of the disease to new regions could be because of global climate; alternatively, Xf could be becoming more tolerant to colder conditions (Kamas et al., 2010). Dr. Don Hopkins, plant pathologist at the University of Florida, has been working on Pierce's disease since 1968. He theorizes the general knowledge pertaining to Pierce's disease has increased over time and more studies are being conducted, revealing newly discovered infected sites that may have been present all along (Kamas et al., 2010). Whatever the case may be, there is no denying Pierce's disease has expanded to non-traditional-commercial-grape-producing states, including Oklahoma.

Symptoms and Detection Technologies

Even though there is a difference in symptoms severity from region to region, actual symptoms do not vary. The most common diagnosis of Pierce's disease is using visual symptom identification. These symptoms include wilting and premature defoliation, dry brown leaf scorch with a green, red and/or yellow boarder and "match sticks" where leaves have fallen and the petiole remains (Smith, 2019). Pierce's disease can also cause the berries to cluster and does not allow for the berries to mature or causes "raisins" (Figures 2.1-2.4) (Kamas et al., 2010). Pierce's disease symptoms are perennial and emerge with hot, dry climate which usually occurs late in Oklahoma summers (Smith, 2019).

Other than the "matchstick" symptom, visual diagnosis is not definite, and the wrong diagnosis can lead to wrong vineyard management (Galvez et al., 2010). Other reliable diagnostic methods are bacterial culturing, enzyme-linked immunosorbent assay (ELISA), and polymerase chain reaction (PCR); however, these are dependent on technology availability and each has its own limitations (Galvez et al., 2010). The reliability of each technique varies depending on sample size, timing and the plant tissue being tested. Culturing the pathogens and ELISA are difficult during early season because there are low population numbers and sample sizes. PCR techniques are currently the most sensitive, economic, fast, and reliable methods of early Pierce's disease detection (Galvez et al., 2010).

Figure 2.1

Pierce's Disease Symptom of Leaf Necrosis (Blaauw et al., 2019).

Figure 2.2

Pierce's Disease of Leaf Blade Abscission from the Attached Petiole Causing "Matchstick" Appearance (Blaauw et al., 2019).

Figure 2.3

Pierce's Disease Symptom of "Islands" of Green Tissue on Primary Grapevine Shoots that are Normally Lignified and Brown at this Stage (Blaauw et al., 2019).

Figure 2.4

Pierce's Disease Symptom of Berry Cluster and "Raisining" (Blaauw et al., 2019).

Pierce's Disease in Oklahoma

Xylella fastidiosa infections have been found in oak, mulberry, American elm, and sycamore in Oklahoma, causing bacterial leaf scorch in these trees (Smith et al., 2009). Pierce's disease was first identified in Oklahoma in August 2008. It was found in a backyard in Canadian County that only contained a few vines (Smith et al., 2009). Infected plants were rogued (removed) and destroyed. The disease was subsequently found in other locations throughout the state, unlikely linked to the initial discovery.

Texas has a growing grape industry with confirmed cases of Pierce's disease in all parts of the state (Kamas et al., 2010). The most efficient vector of Pierce's disease, known as the glassy winged sharpshooter, *Homalodisca vitripeninis,* is found in Texas (Hail et al., 2010). The rising annual temperatures in Oklahoma may provide a favorable habitat for this species to move into the state, raising concerns this vector will begin attacking vines in Oklahoma (Wallace, 2018).

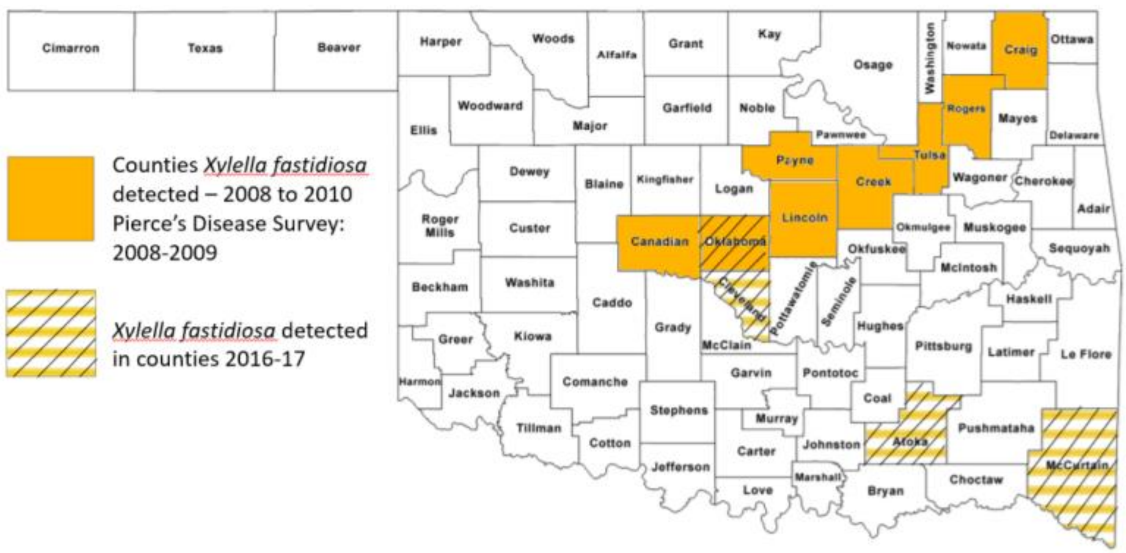
After the first report of Pierce's disease in Oklahoma in 2008, a survey was conducted to determine where the disease was occurring in the state. The survey depended on suspect grape samples being submitted to the diagnostic lab for verification. The samples were tested at the Plant Diagnostic and Insect Diagnostic Lab at Oklahoma State University, which confirmed whether submitted plant samples were positive for the presence of Xf (Wallace, 2018). These results showed Pierce's disease was present in eight Oklahoma counties (Wallace, 2018). When the next survey was conducted in 2016, Cleveland County showed cases of Pierce's disease. Again, another survey was administered in 2017, and Pierce's disease was found in two southeastern Oklahoma counties, Atoka and McCurtain (Wallace, 2018). There is now a total of 11 confirmed counties with confirmed Pierce's disease in Oklahoma (Figure 2.5).

Oklahoma Climate and How it Affects Vines

Climate is the predominant factor to be considered with the development of Pierce's disease in Oklahoma and other Midwestern states (Galvez et al., 2010). Unlike northern, cool-

Figure 2.5

Distribution of Xylella fastidiosa (Pierce's disease) in Oklahoma counties in 2008-2009 and 2016-2017 (Wallace, 2018)



*Oklahoma county was detected in the first survey in 2008 and again in 2016

cold states, Oklahoma has many challenges for premium and consistent grape production. This is because Pierce's disease has shown an intolerance to cold temperatures and high elevations (Stafne, n.d.). With Oklahoma being very humid and having hot summers and mild winters, the state provides a good habitat for diseases such as Pierce's disease (Oklahoma Climatological Survey, 2018; Appel et al., 2010). The hot and dry weather in the state can enhance Pierce's disease symptoms.

The severity of infected vines depends on how long the vine has had the disease (Appel et al., 2010). Producers must make educated decisions when choosing optimal varieties of grapes to plant. The diverse climate in Oklahoma requires vines that can adapt to the cold and heat. They also must be resistant to fungal diseases and withstand the variable soil types around the state (Stafne, n.d.).

Grape characteristics ideal for Oklahoma climate must include the following: vine hardiness, correct vine ripening time (dependent on grape variety and geographical location), quality and vigor of the fruit and vine, tolerance to diseases and insects, market outlet, and requirements of the processor or consumer who will be purchasing the crop. The varieties grown in the Midwest are considerably different compared to those grown in California, meaning there is little to no overlap of educational information pertaining to Pierce's disease (Galvez et al., 2010). The lack of information is not only because of the difference in climate, but also because of the difference in relative susceptibility to diseases among grape varieties.

Two popular grape varieties grown in Oklahoma are Cabernet Sauvignon and Chardonnay. Even though these two grape varieties are popular, they are not as vigorous as some Oklahoma producers prefer. Many Oklahoma producers lean towards hybrid varieties, such as Cynthiana, and tend to grow an array of varieties so they can harvest throughout the season (Nuyaka Creek Winery, n.d.). Table 2.1 shows some of the best grape varieties to grow in Oklahoma.

Transmission of Pierce's Disease in Oklahoma

There are three requirements for successful pathogen transmission (Galvez et al., 2010). First, the pathogen must be acquired by a vector from a diseased host plant. This happens while feeding on stems, leaves or woody branches that harbor Xf. During vector feeding, the pathogen then attaches itself to the vector's foregut. Some microscopy studies have shown the pathogen forms a biofilm in the foregut and are polarly attached to the cuticle. This cuticle is shed at each molt (Galvez et al., 2010), therefore, bacteria are also shed and must be reacquired through feeding (Overall & Rebek, 2015). Once the vector acquires the pathogen from an infected host plant, it will continue to feed on other plants, introducing bacteria into a new host (Galvez et al., 2010).

Table 2.1

A list of best grape varieties to grow in Oklahoma (Carroll, 2017).

Variety	Type	Disease Susceptibility	Principal Use	Winter Hardiness
Baco Noir	Hybrid	Highly	Wine	Fair
Cabernet Sauvignon	Vinifera	Highly	Wine	Good
Challenger	Hybrid		Table	Fair
Chambourcin	Hybrid	Highly	Wine	Poor
Chancellor			Wine	Good
Chardonnay	Vinifera		Wine	Good
Chenin Blanc	Vinifera	Highly	Wine	Fair
Cynthiana	American	Low	Wine	Good
Mars (Seedless)	Hybrid	Slightly	Table	Medium
Riesling	Vinifera	Highly	Wine	Fair
Sauvignon Blanc	Vinifera		Wine	Fair
Saturn	Hybrid	Moderate	Table	Fair
Vanessa	Hybrid	Highly	Table	Good
Venus	Hybrid	Slightly	Table	Fair

The glassy-winged sharpshooter (GWSS) is the most efficient sharpshooter vector of Xf (Overall et al., 2015). The native, North American vector can fly further distances, feed on more hosts and is found in more diverse habitats than other sharpshooters, making it harder to manage (Purcell et al., 2000). Glassy-winged sharpshooter is the most important vector in Texas and California because it has a wide host range and can feed on woody tissues, whereas other vectors cannot (Overall & Rebek, 2015). Relative to other sharpshooters, GWSS also has a greater dispersal ability, allowing for the potential of greater spread of the disease (Almeida & Purcell, 2003; Redak et al. 2004).

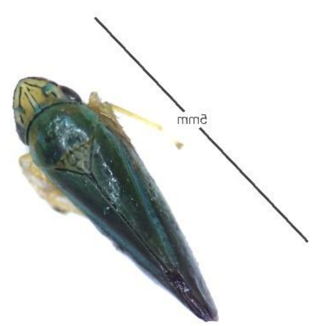
There have been few reports of GWSS in Oklahoma; however, the state does harbor an abundance of vectors capable of transmitting Xf to plants. The three key vectors for Pierce's disease in Oklahoma are *Graphocephala versuta* (Say), *Oncometopia orbona* (F.), and *Graphocephala coccinea* (Förster), with *G. versuta*, being the most common. *Graphocephala hieroglyphica* (Say), *Paraulacizes irrorata* (F.) and *Cuerna costalis* (F.) are also potential vectors found in Oklahoma, but these species have not been found in great numbers and have not been determined to be able to transmit Xf (Overall & Rebek, 2015).

Graphocephala versuta

Graphocephala versuta has green forewings with several black tooth-like markings on the tips of the forewings. The top of the head is light brown and the body has a light blue stripe, sometimes bordered by orange on both sides, running diagonally along each forewing. These sharpshooters are about 5mm in length and are the most prevalent vector of Pierce's disease in Oklahoma (Figure 2.6) (Overall & Rebek, 2015).

Figure 2.6

Graphocephala versuta (Overall & Rebek, 2015)



This species feeds on ragweed, grape, sunflower, okra, plum, blackberry, peach, cherry, and other deciduous trees (Overall & Rebek, 2015). *Graphocephala versuta* can be found mostly in the southern United States and can spread Pierce's disease and Phony Peach disease (Turner, 1949; Myers et al., 2007).

This insect is active in Oklahoma vineyards from June to August, with a peak in late-June to mid-July. *Graphocephala versuta* occurs throughout the whole growing season, but inoculative vectors (vectors capable of transmission) do not occur until mid-late June (Overall & Rebek, 2015).

Oncometopia orbona

Oncemetopia orbona has a large, broad, orange head. Because of these features, which is why it is sometimes referred to as the "broad-headed sharpshooter" (Clark, 2015). This is the largest of the three prominent sharpshooters in Oklahoma, with adults reaching up to 12mm long (Overall & Rebek, 2015) (Figure 2.7). Like *G. versuta, O. orbona* has light blue and black speckles on the forewings and pronotum. Sometimes, females will have white patches called brochosomes, which contain proteins that are smeared onto eggs to prevent desiccation (Overall & Rebek, 2015). Preferred food sources for *O. orbona* include ash, honeysuckle, blackberry, grapes, okra, peach, and Johnson grass (Turner & Pollard, 1959). These insects are found

Figure 2.7

Oncometopia orbona (Overall & Rebek, 2015)

throughout the eastern United States and can spread Pierce's disease and Phony Peach disease (Overall & Rebek, 2015).

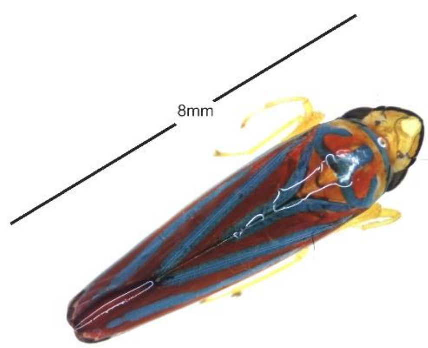
It is assumed from data extrapolated from Oklahoma tree nurseries that *O. orbona* is present in vineyards from late May through late August with a peak in late July. From the same data, it is thought there is only one generation per year in Oklahoma (Overall & Rebek, 2017).

Graphocephala coccinea

Graphocephala coccinea is known as the "candy-striped-leafhopper," because of its prominent coloration. It has a yellow head and a black stripe that runs through the eyes and along the margin of the head. The abdomen and legs are also a bright yellow and the forewings and pronotum have alternating red and blue stripes. Adults are 8 mm in length (Figure 2.8) (Overall & Rebek, 2017). This insect is found in all the United States, as well as parts of Canada and Mexico. Some of this insect's preferred host plants are blackberry, milkweed, rose, thistle, forsythia, and other plants (Young, 1977).

Figure 2.8

Graphocephala coccinea (Overall & Rebek, 2015)



This vector is less common than *O. orbona* in Oklahoma vineyards. There were too few specimens to determine when the peak in abundance occurred, but the most were captured in June (Overall & Rebek, 2017).

Economic Impact of Pierce's Disease

It is hard to determine the exact economic cost Pierce's disease has had on grpae producers due to Pierce's disease. This is especially true for Oklahoma because of limited observations of Pierce's disease, differing varietals resistance levels among the more prominent Oklahoma varieties, limited information on Oklahoma grape markets, and grape quality differences. Nonetheless, investing in a vineyard in any region can be a financial burden. In Oklahoma, starting vineyard owners should expect to spend more than $9000 per acre (≈0.4 hectares) for establishment in the first three years (Stafne, 2010). This does not include annual land costs or the cost of living for the producers.

There are five factors influencing vineyard profitability. The first factor is crop yield, which is measured as the number of tons of grapes grown per acre and varies with different grape varieties. The second factor is the initial price of the grape, which also varies by variety as well as quality and the producers' local market (Nuyaka Creek Winery, n.d.). The third factor includes the fixed and variable costs needed to sustain the vineyard. Typically, labor is about 30% of a producers' expenses, and is mostly spent at harvest time (Nuyaka Creek Winery. n.d.). The fourth factor is similar to the third and includes capital costs such as cost of land, irrigation and equipment. Irrigation is an important factor in Oklahoma vineyards, especially in the hot summer months. Lastly, producers must consider gearing. Gearing, or leveraging, is the level of debt used to finance the vineyard. It is important producers are aware of this and do not overextend or under-invest in this area (Nuyaka Creek Winery. n.d.).

Initial vineyard investment is great with little return until the third year when the vines are established and start to bear fruit to be harvested and sold. It is not until the fifth year that vines are fully productive; once they have reached this point, they can produce a harvest from 25-40 years if managed and cared for correctly (Nuyaka Creek Winery. n.d.).

Pierce's disease can infect a vine at any stage of growth, but the vine can live with the disease between 1-5 years (Tumber et al., 2014). Even if the vine shows no symptoms, Xf can still be transmitted to other vines. This is an automatic economic loss because once a vine is infected the only cure is to remove it from the vineyard. A new vine can be planted to replace the old one, but the new vine will take at least 3 years before it will be mature enough for harvest and therefore, generate revenue.

The grape industry in the United States is valued at around $30 billion, and Pierce's disease is a huge threat (Sanscartier et al., 2012). Since the 1880s when Pierce's disease was first detected, it has caused a decline of more than 35,000 acres of vineyards in Southern California (Galvez et al., 2010). In 1999, Temecula, CA experienced a major outbreak of Pierce's disease (Tumber et al., 2014). California then implemented several programs to help offset the financial burden vineyard owners experience because of Pierce's disease infection. Millions of dollars were invested in research and preventative measures. Studies show that annually $48.3 million is spent on prevention by Californian government agencies, nurseries, and the University of California system. This funding is to help ease the average value of vines lost to Pierce's disease in California, which is approximately $56.1 million (Tumber et al., 2014).

Oklahoma's neighboring state, Texas, has also had its issues with Pierce's disease. Since the transition of Pierce's disease is gradual, rather than abrupt, this may be why Oklahoma is slowly starting to see the effects of the disease (Hopkins & Purcell, 2002). Many states, like Texas, have adapted research from California about pest prevention and management regarding Pierce's disease (Kamas et al., 2010.).

The Oklahoma Grape Industry Council (OGIC), a non-profit organization that represents 90% of the commercial grape and wine industry in Oklahoma, has been a major player in helping grape growers in the state (Frank, Rimerman and Co., 2010). In 2010, OGIC hired Frank, Rimerman and Co. LLP from California to consult and assess the economic value of the state's wine and grape industry (Wallace, 2018). The estimated economic impact of the industry in Oklahoma was $98.5 million. This value includes salaries, wine sales, tourism, contributed taxes to the state and local economy, and federal tax revenue (Frank, Rimerman and Co., 2010). Table 2.2 shows the breakdown of these values.

Table 2.1

Economic Impact for Oklahoma Wine, Wine Grapes and Vineyards (Frank, Rimerman and Co., 2010)

Economic Category	**Value**
Total Oklahoma Economic Impact (direct, indirect, and induced)	$98.5 million
Full-time Equivalent Jobs (total impact)	840
Wages Paid (total impact)	$23 million
Wine Product (Cases)	30,000
Retail Value of Oklahoma Wine Sold	$4 million
Vineyard Revenue	$311,000
Number of Wineries	51
Number of Grape Growers	139
Grape-Bearing Acres	490
Wine-Related Tourism Expenditures	$13 million
Number of Wine Related Tourists	134,000
Taxes Paid: Federal& State	≈$5 million-$6million

Management

The use of integrated pest management (IPM) practices is recommended over conventional methods. This is to reduce the use of chemicals and avoid toxicological and ecological damages pesticides can cause. Integrated pest management provides many solutions for dealing with pest problems, including chemical management, but the overall goal is to reduce dependence on conventional pesticides. Some IPM methods include using natural enemies to manage pests, planning for pest problems before they occur and using reduced-risk or target specific pesticides over conventional pesticides (Rebek et al., 2013).

The use of chemicals is needed under certain circumstances. Although there are no pesticides that control Xf, there are several insecticides to help manage the sharpshooter vectors. Some registered insecticides include foliar-applied acetamiprid and soil-applied imidacloprid and thiamethoxam. These neonicotinoids are the most effective insecticides for controlling sharpshooters and other leafhoppers, thereby inhibiting bacterial transmission and Pierce's disease spread (Bethke et al, 2001). Some field studies have shown the use of neonicotinoids slowed the rate at which Pierce's disease spreads and decreased the population density of sharpshooters (Almeida et al., 2005).

Growers must monitor for the presence of insect vectors in the vineyard, especially during peak months of activity (Rebek & Overall, 2017). To assist with monitoring, growers can use 3"x5" double-sided, yellow sticky cards placed evenly around the vineyard perimeter and diagonally through the center. For Oklahoma vineyards that are usually 2 acres (0.81 hectares) or less, 12-16 sticky cards should be sufficient and should be checked twice a week (Rebek & Overall, 2017). As soon as the vectors are detected in the vineyard, insecticides registered for control of leafhoppers on grapes should be applied.

Along with monitoring vector presence, there are other healthy habits producers should adopt not only to prevent Pierce's disease, but also other diseases and keep their vines as healthy as possible. Grapevines must be pruned every dormant season (just before bud break) in order to get the maximum yield of high-quality fruit without reduction of cold hardiness (Stafne, 2010). When pruning, it is important to leave one set of clippers in a sanitation bucket and switch clippers between vines so mechanical transmission does not occur (Smith, 2019).

Pierce's disease and other maladies can be transmitted when producers propagate from their own or others' cuttings. This practice is discouraged, but if producers choose to do this, they should have mother plants screened for pathogens prior to planting. The best method is to refrain from using cuttings from friends, neighbors or the home vineyard, and purchase plants from reliable grapevine nurseries that are certified to be free of pathogens (Smith, 2019).

It is also important the vineyard has sound weed control. Texas has shown evidence that 100-ft or more “buffer zones” free of weeds around vineyards reduces initial infections. The use of a cover crop, like cool-season grasses within each row of the grape vines, as well as herbicide strips around vines, could help reduce pathogen spread.

If a vine is infected there is currently no cure and the vine must be removed (Rebek & Overall, 2017). Combining all these management practices does not guarantee the stop of Pierce’s disease or other diseases from entering or spreading within the vineyard; however, these tactics greatly reduce the risk of infection and subsequent economic loss.

CHAPTER III

METHODOLOGY

Introduction

This chapter contains methods and procedures used to conduct this study, including approval by the Oklahoma State University Institutional Review Board (IRB), research design, instrumentation, validity, reliability, population, data collection and data analysis.

Institutional Review Board (IRB)

Oklahoma State University policy and federal regulations require review and approval for research involving human subjects before research can begin. This is to protect the welfare of human subjects during the study. OSU IRB reviewed the application and approved the research design on April 16, 2020 (see Appendix A). The IRB application number assigned was IRB-20-201.

Research Design

A survey research method was used to determine Oklahoma grape producers' knowledge of Pierce's disease, ability to identify Pierce's disease, and ability to identify insect vectors for Pierce's disease. In addition, this method was used to understand Oklahoma grape producers' knowledge and use of integrated pest management techniques.

According to Creswell (2012), survey research designs can be used to determine knowledge, attitude, perceptions, opinions or characteristics of a population or sample. Creswell (2012) noted a survey design can be used to learn more about a population. Given the nature of the research objectives of this study, I determined an online questionnaire was the best approach for collecting data.

Population

The population for this study consisted of Oklahoma grape producers according to the Oklahoma Grape Industry Council (OGIC). I used the OGIC email list as my population frame, which included 63 grape producers in Oklahoma. It is important to note there could be more Oklahoma grape producers that were not part of the population frame used for this study.

Instrument Design

The questionnaire used to collect data for this study was created using an experience management platform, Qualtrics®, designed to allow for gathering, analyzing and acting on core business data. This platform allowed the researcher to create and administer the questionnaire online and receive responses in the same manner. Using Qualtrics®, the questionnaire was created with a variety of question types including multiple choice, text entries, and matrix tables. The survey contained 17 questions and took participants approximately 5-7 minutes to complete (see Appendix B).

The questionnaire begins with questions about the demographics of participating Oklahoma vineyards and then flows into general questions about pest management practices in vineyards. The end of the questionnaire aims to address Oklahoma grape producers' knowledge of basic Pierce's disease symptoms and presence within a vineyard. These three topics allow for analysis of the producers' overall knowledge of Pierce's disease and gives some insight on the status of the disease throughout the state.

Survey Details

The questionnaire began with an introduction section, covering the purpose of the study, what to expect, investigators contact information, and a participant agreement acknowledgement. This introduction also included OSU IRB contact information so respondents could know about their rights as a research volunteer.

Respondents began the questionnaire once they agreed to participate in the study and verified they were at least 18 years of age. Introductory questions were designed to ease respondents into the survey tool. These questions focused on IPM use and where producers acquired their knowledge of pest management. This information helped gauge the most often used sources of information.

Following the introduction, the questionnaire addressed the demographics of the vineyard, e.g. location, nature of the business, and volume of business activity. This information allowed me to compare vineyard size, location, vineyard classification (commercial, hobby, or other) and harvest value of production with susceptibility to Pierce's disease later in the questionnaire.

The second major section of the questionnaire assessed the viticulturalist's knowledge and practice of integrated pest management. Following the Greenhouse IPM survey, respondents report their use of specific IPM strategies (Rebek, et al., 2013). The purpose of this section was to determine if producers were using the recommended management techniques for their vines. This helped determine a knowledge baseline pertaining to a more detailed line of questioning regarding Pierce's disease. This section also showed whether Oklahoma producers have received education or training on proper vineyard management.

This section was on a frequency scale and allowed the participant to answer with *Always*, *Sometimes*, *Rarely* or *Never*. These questions were designed to address how active the producer was in their vineyard and the type and regularity of pesticide application. This included cultural and physical control, biological control, and chemical control methods (Rebek, et al., 2013).

Cultural and Physical

- Inspecting plants for pests and diseases before applying pesticides
- Sanitizing tools used in the vineyard
- Relying on calendar sprays to manage pests

- Being proactive in problem solving

Biological

- Using natural enemies to manage pests
- Using established treatment thresholds for common arthropod pests

Chemical

- Using reduced-risk or target specific pesticides over conventional pesticides

With the help of the demographic questions, the end of the questionnaire gave insight into where Pierce's disease was in the state, how many participating vineyards had been affected by Pierce's disease, and overall knowledge and awareness of the disease. These queries were specific to Pierce's disease in Oklahoma and challenged producers' knowledge on the subject.

These questions asked the respondents if they could identify Pierce's disease vectors, symptoms and natural enemies of the vectors. This section helped determine the respondent's knowledge about Pierce's disease and if they could detect the disease if introduced into the vineyard. This will allow the investigators to fill information gaps in the future and give producers the information they need to have a healthy, high-quality vineyard.

The last line of questions in the survey challenged producers' knowledge about the status of Pierce's disease in Oklahoma. These questions allowed for *yes*, *no* or *unsure* responses. This will determine if producers knew which Oklahoma counties had confirmed cases of Pierce's disease and if they knew of neighboring vineyards that had been impacted by Pierce's disease. It also asked if the producers' own vineyard had been exposed to Pierce's disease and if the presence of Pierce's disease in the vineyard had been verified by a diagnostics laboratory test.

The last question, provided five pictures of sucking insect pests commonly encountered in vineyards, including sharpshooters, which are the most common vector of Pierce's disease (Mizell et al., 2015). The questionnaire asked for the participant to identify the three most common insects that transmit Pierce's disease in Oklahoma. The correct responses were *Graphocephala versuta,* which is the most common vector of Pierce's disease in the state, followed by *Oncometopia orbona* and *G. coccinea.*

Validity

Validity in research is defined as "the accuracy a study answers the study question or the strength of the study conclusions" (Sullivan, 2011). In surveys, validity refers to the accuracy of measurement (Sullivan, 2011).

The instrument used in this study was reviewed for content and face validity by a panel of experts. These experts included of three individuals within different departments of Oklahoma State University and were selected based on their knowledge of Pierce's disease vectors and economics and their expertise in online questionnaire design.

The panel members and I reviewed the Greenhouse IPM survey that was used to determine attitudes and practices of IPM techniques to fill information gaps in the future and determined what content was applicable to the current study and what needed to be added or revised (Rebek, et al., 2013).

After changes regarding grammatical errors, clarity, word choice and additions/deletions were made, an online link was sent to the panel of experts to review. Final revisions were made, and the panel members agreed the survey was ready to be administered to potential respondents.

Reliability

Reliability is "whether an assessment instrument gives the same results each time it is used in the same setting with the same type of subjects" (Sullivan, 2011).

Cronbach alpha is used to measure internal consistency or determine how closely related items are as a group (Goforth, 2015). Results for a cronbach's alpha analysis range between zero and one. The closer to one, the more closely relatable the items resulting in higher reliability (Goforth, 2015). In social science research anything above an a=.70 is considered a reliable study.

I did not conduct a pilot study given the small size of this population. The reliability analysis for this study was run post-hoc. I ran a cronbach's alpha on the ten scaled items to determine internal consistency. The resulting cronbach's alpha was a=.869. The questionnaire was deemed reliable.

Data Collection

According to Dillman, Smyth, and Christian (2014), researchers must employ a convenient questionnaire that is easy to respond to for it to be effective. In today's digital age, this often includes web-based questionnaires, and the researcher emailing potential participants with a link that will automatically open in a web browser when clicked (Dillman et al., 2007).

The majority of this study's participants were initially informed of the upcoming research questionnaire at the OGIC Annual Oklahoma Wine Conference and Trade Show on February 10, 2020. This was the first contact with potential participants. They were met face-to-face at this event and shown a presentation about Pierce's disease and the impact it could have on unprotected vineyards. They were also informed an email would be sent out after the March planting season with a link to an online questionnaire designed to help guide future educational and informational efforts on Pierce's disease (Appendix C).

Participant Confidentiality

The responses in this questionnaire were kept anonymous to protect the identity of the participants. I did not collect the names or any information that could lead to identification of the participants. Only aggregated data was reported so there were no identification concerns.

All data were kept confidential and secured on a password-protected computer after download form the Qualtrics® site for analysis. Only my committee members and I had access to the data during the analysis process.

Questionnaire Administration

All potential participants were contacted via email on April 6, 2020, from the OGIC email list informing them of the research being done and asking for participation.

Three and a half weeks later, on April 28, 2020 an email was sent to the OGIC's email list asking for participation in the study and included a link to the questionnaire. The request indicated that only one representative from the vineyard should complete the questionnaire. There were seven responses received after this initial contact.

A second email was sent on May 13, 2020, to remind producers about the survey and again ask for participation. There were 20 new responses following this contact.

The final email was sent June 18, 2020, as a "Thank you" to the producers who chose to participate and a last encouragement for those who had not. This contact resulted in two additional responses, giving me a total of 22 survey responses, or a response rate of 34.92%. Unfortunately, after more fully analyzing the data, four responses were incomplete leaving only 18 totally complete responses to analyze. This resulted in an adjusted response rate of 28.57%.

Nonresponse Error

Nonresponse error is the result of not all people who were sent the survey completing and returning the survey, and if they would have done so, it would have provided a difference in the distribution of answers (Dillman et al., 1998). Even though it is not possible to determine respondents from nonrespondents, it is likely only a certain amount of people who receive the survey will return it completed (Mariger & Leising, 2003). It is suggested that nonresponse error can be a problem even if a small number of people do not return or complete the survey (Dillman 1994).

It is also suggested that if less than 75% response rate is achieved, the researcher should try to compare respondent characteristics with those of the rest of the population or try to describe how respondents are different from nonrespondents or compare early to late respondents (Ary et al., 1996; Linder et al., 2001).

Many steps were taken to minimalize the nonresponse error, by following the Don Dillman, Tailored Design (Dillman, 2000; Dillman, 2014). First, a presentation was given at the OGIC annual conference, discussing Pierce's disease and the threat it could have on a producer's vineyards. This was to create an awareness among growers of the need for more research on Pierce's disease in Oklahoma. Next, an email was sent to 63 Oklahoma grape producers' around the state, including those who attended the conference, informing them an email with a survey would soon be sent to them. Following, an email with the questionnaire link was sent to the same producers. A follow-up email and a thank you email with the questionnaire link were the final two contacts.

Following data collection, I did a visual comparison of the responses between early and late respondents (Linder et al., 2001) and determined the responses were similar leading to the assumption that nonrespondents would also be similar.

Data Analysis

Once complete and all responses were gathered, I downloaded the data from Qualtrics® for analysis. Data was exported to an Excel file and then imported into the Statistical Package for Social Sciences (SPSS) version 26 for Mac.

The first research objective was to describe selected characteristics of Oklahoma grape producers' vineyard including size, geographic location, vineyard classification, and harvest value of production. Participants responses were analyzed and reported with frequency data.

The second research objective was to Identify Oklahoma grape producers' sources of information for pest management. This was done by asking the respondent where they obtained this information and allowed them to give more than one answer for their information sources.

The third research objective was to determine Oklahoma grape producers' knowledge of Pierce's disease. The questionnaire asked if producers could identify signs and symptoms of Pierce's disease, and if they knew where in Oklahoma the disease is located.

The final research objective was to determine Oklahoma grape producers' knowledge and use of Integrated Pest Management techniques regarding Pierce's disease

This was analyzed and reported with frequency data as well.

CHAPTER IV

RESULTS AND FINDINGS

Research Objectives

The following research objectives guided this study:

1. Describe selected characteristics (size, geographic location, vineyard classification, and harvest value) of Oklahoma vineyards.
2. Identify Oklahoma grape producers' sources of information for pest management.
3. Determine Oklahoma grape producers' knowledge of Pierce's disease.
4. Determine Oklahoma grape producers' knowledge and use of Integrated Pest Management techniques regarding Pierce's disease

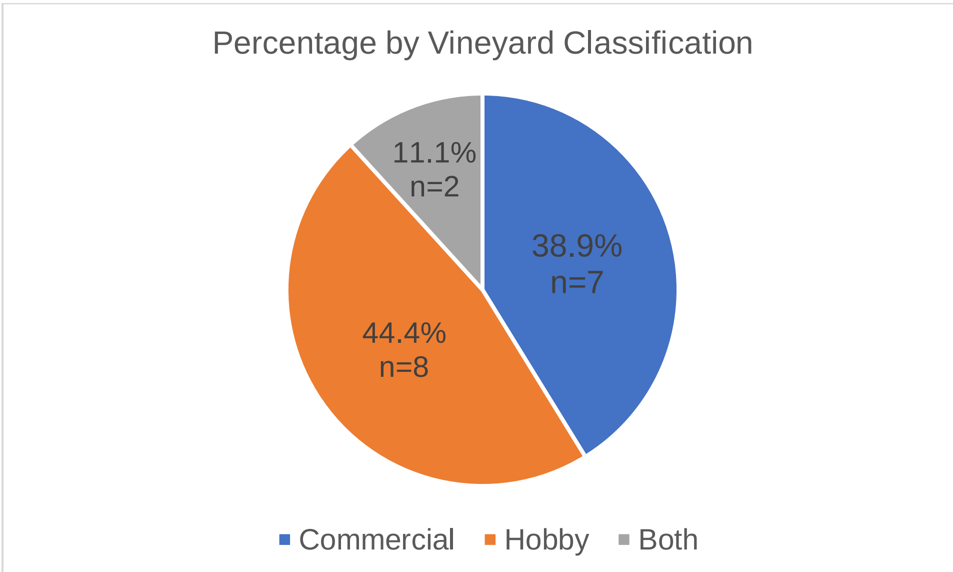
Findings Related to Objective 1

Objective one was to describe selected characteristics (size, geographic location, vineyard classification, and harvest value) of Oklahoma vineyards. The 18 respondents represented 14 counties (i.e. Caddo, Cleveland, Hughes, Dewey, Johnston, Lincoln, Marshall, McClain, Okfuskee, Oklahoma, Pontotoc, Seminole, Stephens and Washington).

Responding counties were classified as either commercial or hobby vineyards: 38.9% (n=7) were commercial vineyards and 44.4% (n=8) were hobby vineyards, with 11.1% (n=2) identifying as both and 5.6% (n=1) nonresponse (Figure 4.1).

Figure 4.1

Percentage of vineyards that identify as commercial production, hobby production or both.

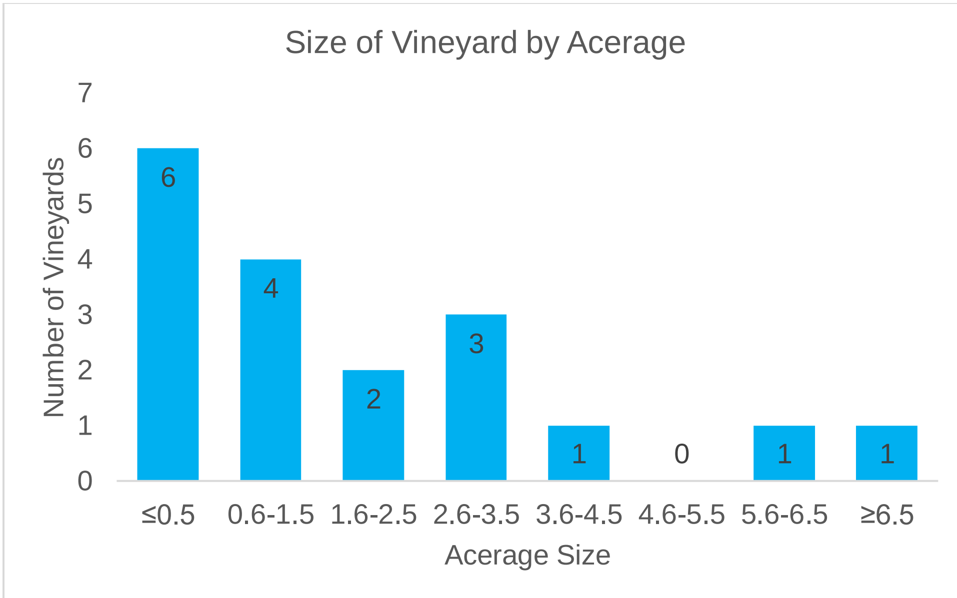


The average size of respondents' vineyards was 2.2 acres (0.89 hectares) and most of the vineyards were less than 1.5 acres (.61 hectares). The smallest vineyard reported was .25 acres (0.10 hectares). The largest vineyard was an outlier and was reported as 10 acres (4.04 hectares), as seen in Figure 4.2.

Of these, the largest reported harvest value of production from the 2019 harvest was $12,000; however, 77.8% (n=14) left this answer blank resulting in a lack of useful data for any economic impact assesments. The respondents who did answer said they were either unsure of their value of production, or their vines were still in the establishment stage and have yet to produce a harvest.

Figure 4.2

Represents the size of Oklahoma vineyards by acreage.



Findings Related to Objective 2

Objective 2 of the study was to identify Oklahoma grape producers' sources of information for pest management. This also included asking which sources of information were considered most useful for making pest management decision. The results indicated the top information sources were the Oklahoma Grape Industry Council (OGIC), the internet, the state extension viticulture specialist (Becky Carrol), local extension specialists, and other growers. Many also answered Dr. Eric Rebek and viticulture specialists from Texas A&M, specifically Michael Cook. Most respondents (83.4%; n=15) also relayed they either always or sometimes knew where to find alternative pest control information when needed.

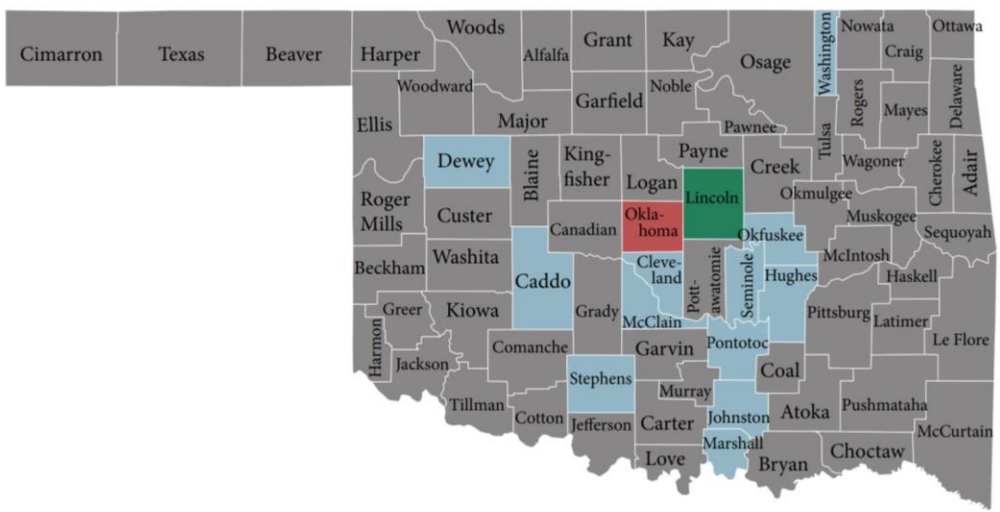
Findings Related to Objective 3

Objective 3 was to determine Oklahoma grape producers' knowledge of Pierce's disease. There were respondents from 14 counties participating in this study. Of the 14 counties, two reported having had Pierce's disease in their vineyards. These two counties were Lincoln and Oklahoma and made up for 3 of the respondents (two in Oklahoma county) (Shown in Figure

4.3). The two vineyards in Oklahoma county that reported having been diagnosed with Pierce's disease in a lab. Only 1 respondent (5.6%) reported knowing where in Oklahoma Pierce's disease has been identified. The other respondents (94.5%; n=17) did not know where in Oklahoma Pierce's disease has been detected or if their neighbors have had the disease in their vineyard.

Figure 4.3

Oklahoma counties represented by responding vineyard owners, including counties reporting Pierce's disease.



*Oklahoma county detected Pierce's disease in the survey in 2008 and in 2016

*Lincoln county detected Pierce's disease using visual detection

Findings Related to Objective 4

Objective 4 was to determine Oklahoma grape producers' knowledge and use of Integrated Pest Management techniques regarding Pierce's disease. Respondents were asked a series of questions regarding their IPM use, and practices and their ability to identify insect vectors of Pierce's disease.

Of the 18 responses, 55.6% (n=10) said they were familiar with IPM tactics, but only 44.4% (n=8) said they had used IPM in the last 12 months. About 16% (n=3) of respondents said they were not familiar with IPM and 22.2% (n=4) said that they had not used IPM in the last 12 months. Others (27.8%; n=5) relayed they were unsure what IPM was or if they had used it in the last 12 months.

Like the results found from the Greenhouse IPM survey, respondents reported their use of specific IPM strategies (Rebek et al., 2013). This included cultural and physical control, biological control, and chemical control methods (Table 4.1). Of these responses, 44.4% (n=8) reported using conventional control methods only and 44.4% (n=8) reported using both conventional control and IPM strategies. There were 11.1% (n=2) nonresponses.

Respondents were also asked about vector identification of Pierces disease, as well as symptoms and plant damage. There was a very diverse response of those who believed they could identify plant damage and symptoms of Pierce's disease (Table 4.2).

The last question tested whether respondents could identify the three most common insect vectors of Pierce's disease in Oklahoma. Only 3 (n=16.7%) were able to identify all three Oklahoma insect vectors capable of transmitting Pierce's disease in Oklahoma correctly. There was 1 (n=5.6%) respondent that chose two of the correct vectors and 27.8% (n=5) respondents were able to identify 1 correctly. This was the *O. orbona,* which is one of the less common transmitters of Pierce's disease in Oklahoma. Also, it is important to point out that there were only five pictures, so it was likely many respondents would get at least one right.

Table 4.1

Responses for use of specific IPM strategies producers currently use.

Question Prompt	Always	Sometimes	Rarely	Never	Nonresponse
I am the primary decision maker for managing plant disease and insect pests.	n=14 (77.8%)	n=3 (16.7%)	n=1 (5.6%)	n=0 (0%)	n=0 (0%)
I rely on calendar sprays to manage pests.	n=4 (22.2%)	n=13 (72.2%)	n=0 (0%)	n=1 (5.6%)	n=0 (0%)
I monitor/scout for pests before applying pesticides.	n=12 (66.7%)	n=5 (27.8%)	n=0 (0%)	n=0 (0%)	n=1 (5.6)
I use established treatment thresholds for common arthropod pests.	n=6 (33.3%)	n=8 (44.4%)	n=2 (11.1%)	n=0 (0%)	n=2 (11.1%)
I use reduced-risk/target-specific, pesticides over conventional pesticides.	n=5 (27.8%)	n=10 (55.6%)	n=1 (5.6%)	n=3 (16.7%)	n=2 (11.1%)
I rotate among pesticides with different modes of action to manage resistance.	n=9 (50.0%)	n=4 (22.2%)	n=2 (11.1%)	n=0 (0%)	n=3 (16.7%)
I use natural enemies (predators, parasites, and pathogens) to manage pests.	n=2 (11.1%)	n=5 (27.8%)	n=4 (22.2%)	n=5 (27.8%)	n=2 (11.1%)
I plan for pest problems before they occur.	n=4 (22.2)	n=11 (61.1%)	n=1 (5.6%)	n=0 (0%)	n=2 (11.1%)
I use sanitation to effectively reduce pest populations.	n=10 (55.6%)	n=5 (27.8%)	n=1 (5.6%)	n=1 (5.6%)	n=1 (5.6%)
I can identify beneficial arthropods (e.g., natural enemies).	n=3 (16.7%)	n=6 (33.3%)	n=5 (27.8%)	n=3 (16.7%)	n=1 (5.6%)

Table 4.2

Responses for identifying insect vectors of Pierce's disease, damage and symptoms caused by the disease and alternative resources for information.

Question Prompt	Always	Sometimes	Rarely	Never	Nonresponse
I can identify major insect vectors of Pierce's Disease.	n=4 (22.2%)	n=6 (33.3%)	n=2 (11.1%)	n=4 (22.2%)	n=2 (11.1%)
I can identify major plant damage caused by insect vectors of Pierce's Disease.	n=4 (22.2%)	n=7 (38.9%)	n=1 (5.6%)	n=5 (27.8%)	n=1 (5.6%)
I can identify signs and symptoms of Pierce's Disease	n=3 (16.7%)	n=6 (33.3%)	n=3 (16.7%)	n=5 (27.8%)	n=1 (5.6%)

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The Oklahoma grape industry is still young, relative to the largest producing states in post-Prohibition times, and grape producers are trying to navigate the business the best they can with the tools and information they are given. This study showed there is much more education needed for these producers regarding IPM practices and insect vector identification.

No new counties have reported having Pierce's disease since the studies performed in 2008 and 2016; however, of the 14 counties that completed the 2020 survey, two counties have had Pierce's disease in responding vineyards. These two counties were Oklahoma and Lincoln County.

It is possible, however, there are more counties that harbor the disease and producers are unaware. Dr. Don Hopkins, plant pathologist at the University of Florida, theorizes Pierce's disease is present, but producers do not recognize the signs or symptoms. The current study showed the majority of producers could not identify insect vectors of Pierce's disease in Oklahoma. If vectors cannot be identified, then producers will not know when to apply insecticides to keep the disease from spreading, which would result in loss of vines.

Not all responding vineyards have been examined by a professional or had vines tested by a diagnostics lab to determine the presence of Pierce's disease in vineyards. It would be beneficial to conduct another diagnostic survey like the surveys in 2008 and 20016. A future survey could re-sample the vineyards that have already participated is a diagnostic survey as well as new vineyards. Also, it is important that many vineyards from each county be surveyed and possibly visited by researchers to account for all possible vector presence.

With or without diagnostic testing, producers should be monitoring for insect vectors and scouting for plant damage due to Pierce's disease in their vineyards. There are some Oklahoma professionals on whom Oklahoma producers rely; however, many reported using Texas A&M viticulture specialists. This shows there is a need in Oklahoma for a state viticulture specialist. An Oklahoma viticulture specialist could build a team of knowledgeable viticulturalists specialists in the state and could aid with more specific viticulture need as they arise.

If this study is repeated, an in-person element of educational programming should be added so producers can be made more aware of the disease and its presence in the state. Hosting a field day for grape producers, with the subject being insect vectors or IPM would allow producers to experience first-hand monitoring of insect vectors and using of beneficial pest management practices. Frequent access to field days, conferences, and workshops for Oklahoma grape producers would be beneficial to provide information on current happenings in the industry.

It was difficult to determine economic loss of Pierce's disease in Oklahoma vineyards because of the limited identification of Pierce's disease in Oklahoma vineyards and the lack of vineyards financial data of the vineyards. Ideally, future research will capture adequate financial measures from responding vineyards to estimate the impacts of potential Pierce's disease on costs and revenues. Given the small and variable sizes of Oklahoma vineyards, these assessments may need to be segmented by vineyard size and varieties of grapes produced.

There is still a low threat of Pierce's disease in Oklahoma, however it does exist and needs to be monitored. With more awareness and an increase of knowledge of the disease, producers will be able to identify vectors and plant damage, resulting in a rise in cases of Pierce's disease in Oklahoma.

Overall, this research shows a lack of Oklahoma grape producers' knowledge of Pierce's disease and the vectors that spread the disease. There is a need for more education and research to make producers aware of the threat of Pierce's disease and the methods for identifying and controlling vectors to lessen the impacts of the disease in Oklahoma vineyards. This study hopefully serves as a starting point for future researchers to build upon and shows where information gaps lie so educational needs can be met.

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APPENDICES

APPENDIX A

Oklahoma State University Institutional Review Board

Date:	04/16/2020
Application Number:	IRB-20-201
Proposal Title:	Best Practices for Mitigating Pierce's Disease in Oklahoma Vineyards
Principal Investigator:	Mackenzie Jacobs
Co-Investigator(s):	
Faculty Adviser:	RODNEY HOLCOMB
Project Coordinator:	
Research Assistant(s):	
Processed as:	Exempt
Exempt Category:	

Status Recommended by Reviewer(s): Approved

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in 45CFR46.

This study meets criteria in the Revised Common Rule, as well as, one or more of the circumstances for which continuing review is not required. As Principal Investigator of this research, you will be required to submit a status report to the IRB triennially.

The final versions of any recruitment, consent and assent documents bearing the IRB approval stamp are available for download from IRBManager. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be approved by the IRB. Protocol modifications requiring approval may include changes to the title, PI, adviser, other research personnel, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms.
2. Submit a request for continuation if the study extends beyond the approval period. This continuation must receive IRB review and approval before the research can continue.
3. Report any unanticipated and/or adverse events to the IRB Office promptly.
4. Notify the IRB office when your research project is complete or when you are no longer affiliated with Oklahoma State University.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact the IRB Office at 405-744-3377 or irb@okstate.edu.

Sincerely,
Oklahoma State University IRB

APPENDIX B

Identifying Oklahoma Vineyard Owners Knowledge of Pierce's Disease

Start of Block: Default Question Block

Identifying Oklahoma Vineyard Owners Knowledge of Pierce's Disease

Investigators: Mackenzie Jacobs and Dr. Rodney Holcomb, Agriculture Economics

Purpose: The purpose of this study is to identify Oklahoma grape producers knowledge on Pierce's Disease. This study will also provide insight into the threat of Pierce's Disease in Oklahoma vineyards from an economic standpoint.

What to Expect: This research study is administered online. Participating in this study will require you to complete one questionnaire. You may skip any question(s) that you do not wish to answer. You will only be expected to complete the questionnaire once. It should take you about 10 min to complete.

Contact: Mackenzie Jacobs| 405-496-2212 | mackenzie.jacobs@okstate.edu
If you have questions about your rights as a research volunteer, you may contact Michael Criss, IRB Chair at 223 Human Sciences, Stillwater, OK 74078, 405-744-4325 or irb@okstate.edu.

Participate Agreement: I have read the procedures described above. I voluntarily agree to participate and understand that by clicking "I agree" below, I am consenting to participate in this study and am at least 18 years of age. If you choose not to participate, I will click "I Do Not Agree."

○ I agree

○ I do not agree

Skip To: End of Survey If Participate Agreement: I have read the procedures described above. I voluntarily agree to partici... = I do not agree

Q1 For information about pest management, I rely on (please check all that apply):

- ▢ Local extension educator
- ▢ State extension specialist
- ▢ Industry sales person
- ▢ Other growers
- ▢ Internet
- ▢ Oklahoma Grape Industry Council
- ▢ Other: ____

Q2 Which of these sources do you find most useful when making pest management decisions (please check only one)?

- ◯ Local extension educator
- ◯ State extension specialist
- ◯ Industry sales person
- ◯ Other growers
- ◯ Internet
- ◯ Oklahoma Grape Industry Council
- ◯ Other: ____

Q3 I am familiar with integrated pest management (IPM) tactics.

- ◯ Yes
- ◯ No
- ◯ Unsure

Q4 I have used IPM tactics to manage pests in the last 12 months.

- ○ Yes
- ○ No
- ○ Unsure

Q5 When managing plant pests, I use:

- ○ IPM Strategies
- ○ Conventional Control
- ○ Both

Q6 In which county is your vineyard located?

____

Q7 What kind of vineyard do you have?

- ○ Commercial
- ○ Hobby
- ○ Both

Q8 What is the size of your vineyard (in acres)?

____

Q9 What was last harvest's value of production?

____

End of Block: Default Question Block

Start of Block: Block 1

	Always	Sometimes	Rarely	Never
I am the primary decision maker for managing plant disease and insect pests.	○	○	○	○
I rely on calendar sprays to manage pests.	○	○	○	○
I monitor/scout for pests before applying pesticides.	○	○	○	○
I use established treatment thresholds for common arthropod pests.	○	○	○	○
I use reduced-risk/target-specific, pesticides over conventional pesticides.	○	○	○	○
I rotate among pesticides with different modes of action to manage resistance.	○	○	○	○

I use natural enemies (predators, parasites, and pathogens) to manage pests.	○	○	○	○
I plan for pest problems before they occur.	○	○	○	○
I use sanitation to effectively reduce pest populations.	○	○	○	○
I can identify major insect vectors of Pierce's Disease.	○	○	○	○
I can identify major plant damage caused by insect vectors of Pierce's Disease.	○	○	○	○
I can identify signs and symptoms of Pierce's Disease.	○	○	○	○
I can identify beneficial arthropods (e.g., natural enemies).	○	○	○	○
I know where to find alternative pest control information.	○	○	○	○

End of Block: Block 1

Start of Block: Block 2

Q15 Do you know what counties in Oklahoma have detected Pierce's Disease?

◯ Yes

◯ No

◯ Unsure

Q16 Do your neighbors have Pierce's Disease in their vineyards?

◯ Yes

◯ No

◯ Unsure

Q17 Has your vineyard been exposed to Pierce's Disease?

◯ Yes

◯ No

◯ Unsure

Q18 Has your vineyard been diagnosed with Pierce's Disease by a lab?

◯ Yes

◯ No

◯ Unsure

Q19 Identify the 3 main sharpshooters who transmit Pierce's Disease in Oklahoma.

End of Block: Block 2

End of Survey

APPENDIX C

Email Contact #1

Hello!

This is Mackenzie Jacobs. I attended the Oklahoma Grape and Wine Industry Conference in February, where is was given your email. I hope you have been doing well since then and have been staying healthy.

I am a graduate student at Oklahoma State University and am working on wrapping up my studies. In order to do this, I am conducting research over Pierce's Disease in Oklahoma. To collect data for this research, I will be sending out an online survey via email to grape farmers around the state. It will cover Oklahoma farmer's knowledge on Pierce's Disease and management and prevention techniques. I would appreciate your participation in this study to help Oklahoma grape producers.

Also, I would like to extend any help I can give. With the current pandemic, I am not on OSU's campus every day, but I continue to work closely with many staff members who are well trained in the area of viticulture. Two of which are Becky Carroll (Viticulture Extension Specialist) and Erick Rebek (Professor and State Extension Specialist), along with others in the plant diagnostic labs and enology sectors. If there is anything I can help with regarding soil samples, petiole tests or general questions please let me know.

I look forward to working with you in the near future.

Thank you!

Email Contact #2

Hello!

I hope I find you all healthy and well.

I am a graduate student at Oklahoma State University and am working on wrapping up my studies. In order to do this, I am conducting research over Pierce's Disease in Oklahoma.

Provided to you below is a link to a survey. This survey will help evaluate Oklahoma vineyard owners' knowledge on Pierce's Disease and management so educational needs can be met in the future.

I am asking that you please be so kind as to help by taking this short 5-7-minute survey. I would be very appreciative of you.

Oklahoma Vineyard Owners Knowledge of Pierce's Disease

Thank you kindly.

Email Contact #3

Good morning!

I wanted to reach out again to see if you would be willing to participate in a research survey over Pierce's Disease in Oklahoma. Even if your vineyard is not directly affected by the disease, your participation is still vital to the success of this study.

Below is a link to the survey. This survey will help evaluate Oklahoma vineyard owner's knowledge on Pierce's Disease and management so educational needs can be met in the future.

I am asking if you could please help me finish this study by taking this short 5-7min survey.

Oklahoma Vineyard Owners Knowledge of Pierce's Disease

Thank you kindly,

Email Contact #4

Hello

I want to thank those who have participated in the survey "Oklahoma Vineyard Owners Knowledge of Pierce's Disease." Your participation has not only helped me to complete my studies at Oklahoma State University, but also assist Oklahoma viticulturists in the future by identifying education gaps and further improve Oklahoma vineyards.

If you have not yet had a chance to complete the survey, there is still time. I will be finalizing the results of this study by the end of this week (Friday, June 19) and would appreciate any additional responses. The survey is listed below and takes about 5-7min to complete. This is a chance to help better the Oklahoma vineyard industry.

Identifying Oklahoma Vineyard Knowledge of Pierce's Disease

Thank you again for your time and consideration.

Best,

VITA

Mackenzie R. Jacobs

Candidate for the Degree of

Master of Science

Thesis: IDENTIFYING OKLAHOMA VITICULTURALIST KNOWLEDGE OF PIERCE'S DISEASE

Major Field: International Agriculture

Biographical:

Education:

Completed the requirements for the Master of Science in International Agriculture at Oklahoma State University, Stillwater, Oklahoma in July, 2020.

Completed the requirements for the Bachelor of Science in Agricultural Business at Oklahoma State University, Stillwater, Oklahoma in 2020.

Experience:

Employed as a Teaching Assistant for Agricultural Communications.
Employed as a Graduate Assistant for the Department of International Agriculture.