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Investigation of Peach Fruit Bagging to Produce High Quality Fruit and to Manage Pests and Diseases

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INVESTIGATION OF PEACH FRUIT BAGGING TO PRODUCE HIGH QUALITY FRUIT AND TO MANAGE PESTS AND DISEASES

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ABSTRACT

One of the main challenges of growing high quality peaches in the southeastern United States is to cope with the high pest and disease pressure caused by the humid climate in the region. Bagging fruit at an early stage of fruit development could be a viable way to physically exclude pest and diseases. Experiments were conducted for two consecutive years at a conventional farm and an organic farm and results indicate no consistent differences between treatments in fruit quality parameters, marketable yield at harvest, or post-harvest disease incidence when compared to the control not bagged fruit. Nevertheless, marketable yield in the early season cultivar had a 13% increase in 2015 and the mid-season cultivar had an 11% increase in 2016. The commercial farm had 100% yield in bagged and control treatments except when bags were placed improperly during 2016. Bagging peach fruit appeared to reduce the intensity of red blush but consumer surveys suggested color was not a decisive factor when purchasing the fruit. The benefit from the bags could stem from the increase in price consumers are willing to pay for "grown-in bag" fruits that have less contact with pesticides. More economic analysis needs to be done, but an increase in price could potentially offset the extra cost of labor and bagging material. In a homeowners setting non-bagged fruit was compared to bagged fruit and treated with different chemical applications and results showed that bagging the fruit can have a significant effect on yield high disease pressure.

DEDICATION

To my parents who helped and supported me through everything.

To my graduate student friends who made Clemson feel like a home and not just a place to work.

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I would like to thank Dr. Juan Carlos Melgar for all this help and guidance over these past two years as I earned my degree.

I would also like to thank all of the wonderful professors at Clemson University who helped me learn and grow as a student.

Thanks to the farms that allowed us to use their trees for research and their staff to help us bag fruits.

A special thanks to all the students who took the time out of their busy schedules to help bag and harvest trees.

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INTRODUCTION

Controlling pest and diseases can be a major challenge for both commercial growers and those who grow peaches in their backyards. The southeastern United States has hot and humid summers that allow pests and diseases to thrive in peach trees. Some of the most important pests affecting peach production in the southeastern United States are brown rot (*Monilinia* spp.) and plum curculio (*Conotrachelus nenuphar* Herbst) (Horton et al., 2005). Brown rot is a fungal pathogen that rots the entire fruit (Byrde, 1977). Plum curculio is an insect pest that can inflict damage by laying eggs in young immature fruit which can lead to wormy fruit (Horton et al., 2008). The adults can also cause feeding damage on the fruit as they are ripening (Horton et al. 2008). Specifically, organic growers in the southeastern United States do not have efficacious chemicals to combat brown rot or plum curculio and up to 50 percent of their crop is lost to these pests (J.C. Melgar, personal communication).

Commercial peach production in the United States is economically important, especially the growing organic market (Perez and Plattner, 2013). The state producing the most peaches is California coming in at 604,600 tons of peaches in 2015 (USDA, 2016). South Carolina is second in peach production at 59,700 tons produced in 2015 (USDA, 2016). Georgia produced 33,700 tons in 2015 making the state the third largest producer (USDA, 2016). California is able to take advantage of the growing organic market because production of organic peaches is feasible in the semi-arid climate in the San Joaquin Valley (Perez and Plattner, 2013). However, organic production of peaches in the southeastern U.S. is much harder because of the high pest and disease pressure favored by the climate, and because of the lack of effective organically approved control methods to combat pests and diseases (Ames, 2012). As a consequence, there is only one organic peach farm in South Carolina and none in Georgia.

Fruit bags can be used as a physical barrier to exclude pests from peaches. Adding fruit bags to the pest management program in an organic farm has the potential to increase yield and protect peaches when organic chemicals are not completely efficacious in controlling high incidence of pests or diseases.

In the conventional setting fruit bags may also have the potential to increase profits. Consumers are becoming more concerned about the amount of pesticide used during production and the residues left on their fruit and vegetables (Ames, 2012). If bagged fruit are marketed as "grown-in-bag" it might be sold at a premium. Perhaps, the farms could use a small acreage of their farm for bagged fruit and sell that fruit at a higher price to help increase overall profit for the farm. An additional potential benefit from bagging fruit would be and adjustment of spray schedules and the option to buy less effective chemicals. Expanding intervals between sprays and changing chemical pesticides could help reduce the chance of resistant fungicide development.

Bagging fruit is a practice in numerous other countries (Faci et al., 2014; Jia et al., 2005; Kim et al., 2000; Kitagawa et al., 1992). Outside of the United States, fruit bagging is not exclusive to peaches but has been found to benefit production of bananas, mango, apples, pears, and table grapes (Hofman et al., 1997; Huang et al., 2009; Muchui et al., 2017; Sharma et al., 2014; Signes et al., 2007). In terms of fruit quality, there are conflicting reports on whether the bags have an impact on the fruit quality. The variation between these research studies is likely due to type of bags, fruit, timing of bagging, or climate (Sharma et al., 2014).

Homeowners that grow fruits and vegetables themselves are often reluctant to spray chemicals. In most cases, residents do not have access to the same chemicals as commercial growers. Bagging fruit could benefit those homeowners who choose to produce food with low to no chemical input. Labor cost is typically not an obstacle for hobbyist fruit grower since usually they only grow a few trees in their backyard. Currently there is no research on the feasibility, efficacy, and benefits of bagging peach fruit in a backyard setting.

CHAPTER ONE

LITERATURE REVIEW

Peaches in the United States

Peaches are part of the genus *Prunus* in the Rosaceae family. The peach (*Prunus persica* [L.] Batsch) is related to other important domesticated species including almond (*Prunus amygdalus* Batsch), sweet cherry (*Prunus avium* L.), plum (*Prunus domestica* L.) and apricot (*Prunus armeniaca* [L.] Kostinia) (Hancock, 2012). Domestication of the peach fruit occurred in Western China. (Vavilov, 1951). The arrival of peaches in the Americas was facilitated by Spanish explores who brought the fruit into South America. In North America it was spread by the Native Americans who traded the seeds and spread them westward across the United States (Bassi and Monet, 2008).

The peach fruit has become an important commodity in the United States and other countries around the world. Worldwide peach production reached 22,795,854 tons of fruit in 2014, with China being the leading producer of peaches, producing 12,452,377 tons in 2014 (FAOSTAT, 2017). In the United States, there were 99,790 bearing acres of peach production, which produced 825,415 tons of fruit in 2015 (USDA, 2016). California is the leader in peach production with 604,600 tons (USDA, 2016). South Carolina is the second highest producing state with 59,700 tons being produced, and Georgia produces 33,700 tons, making it the third largest producing state (USDA, 2016). The values of peaches produced in the United States in 2015 was $605,794,000 (USDA, 2016).

The organic peach production in the United States saw a 49% increase between 2008 and 2011 with 21,372 tons being produced in 2011 (Perez and Plattner, 2013). Economically, production of organic peaches reached a value of $20 million (Perez and Plattner, 2013). Most of this growth in organic production occurred in California, where 18,024 tons were produced in 2011 (Perez and Plattner, 2013). The climate of California is semi-arid in the San Joaquin Valley, where most peaches are produced. The average rainfall for Fresno, California is 12.83 inches per year compared to 44.29 inches in Columbia, South Carolina (USGS, 2017). The small amount of rainfall is one of the factors allowing for the success of California's organic peach production. The Southeastern United States has a humid subtropical climate, with hot and humid summer months and mild winters. Wet and hot conditions are ideal for fungal growth and insect emergence. The mild winters allow for fungi and insects to overwinter easily without being killed by low temperatures or large amounts of snow fall. As a result, South Carolina has only one large scale organic farm and Georgia has none.

Peach Pest and Diseases

Some research studies have suggested that bagging can also help control some diseases. For instance, bagging has been proved to reduce black spot caused in Japanese pear, making the fruit easier to grow in Japan (Kitagawa et al., 1992). Other diseases, such as anthracnose and stem end rot, can be a problem for mangos and bagging was shown to decrease in incidence in the 'Keitt' cultivar (Hofman et al., 1997). Also, bagging delayed ripening in 'Perla' black table grapes and helped make their color more uniform across bunches (Signes et al., 2007). However, no literature on the effect of bagging on controlling peach pests and diseases.

The main pests and diseases that cause fruit loss in peaches include insects such as plum curculio, scale, stink bugs, and thrips along with diseases such as brown rot, bacterial spot, and peach scab. Plum curculio (*Conotrachelus nenuphar* Herbst: Curculionidae) is a major pest to peaches and apples in the eastern United States. The weevil produces two generations during the year in the southeastern United States due to the warmer temperatures (Horton et al., 2005). The larva can survive the winter in orchards or in surrounding native hosts (Horton et al., 2005). When adults emerge, they feed on young fruitlets, usually causing them to abort (Hogmire, 1995). If successful oviposition happens, then the larva tunnel through the fruit causing wormy fruit (Horton et al., 2005). The weevil produces a feeding injury on the fruit as an adult, which is usually D-shaped.

Plum curculio is a major problem for organic growers east of the Rocky Mountains because there are no organic methods to effectively control this pest (Horton et al., 2005). Selling the fruit can also be difficult because there is no tolerance for insect damage (Horton et al., 2005). Crop protectants derived from kaolin clay are widely used as deterrent for plum curculio by organic farmers (Ames, 2012), who spray multiple layers of kaolin clay as the fruit matures and grows to improve efficacy (Wise, 2017).

Conventional farmers have a wider range of choices when it comes to controlling plum curculio. Effective chemicals include organophosphates, pyrethroids, and neonicotinoids (Wise, 2017). In adult insects these chemicals are primarily lethal contact poisons (Wise, 2017). Other control methods of this pest species include trapping and the use of entomopathogenic nematodes (Horton et al., 2005; Shapiro-Ilan, 2013).

San Jose scale is a small insect that can reproduce quickly and can damage fruiting wood or limbs from feeding damage. If the infestation of scale is large enough then the fruit show inflamed red lesions that damage the cosmetics of the fruit (Horton et al., 2008). Other peach pests include stink bugs, which feed on green and ripening peaches and leave behind damage from inserting the stylet into the fruit, and thrips, which can cause feeding damage on fruits resulting in skin damage in the form of silvering (Horton et al., 2008).

Brown rot (*Monilinia* spp.) is a fungal pathogen that can cause major yield losses for farmers in the southeastern United States on all commercially grown *Prunus* species (Byrde, 1977). The fungi overwinter in mummies, or dried up fruit, which fall to the orchard floor, or stay attached to the tree (Byrde, 1977). Temperature and moisture initiate the production of spores from the mummies, which are carried to the twigs and blossoms by wind and rain (Biggs and Northover, 1985). Major yield loss occurs when ripening fruit develop brown rot, which may only take 48 hours under optimal conditions. Brown rot occurs in an optimal temperature range of 22.5°C-25°C along with wet conditions (Byrde, 1977). Plum curculio can also transfer brown rot from fruit to fruit as they feed, which can spread the disease to new parts of the orchard (Adaskaveg et al., 2008).

The high temperature and high humidity makes control of brown rot difficult in the southeastern United States (Bernat et al., 2017). In organic farming the primary product used for control of brown rot are sulfur formulations (Ames, 2012). Sulfur products can be used along with kaolin clay for an added layer of protection. Another important control method for organic farmers is cultural control. Sanitation practices such as removing mummies and infected plant materials from the orchard can reduce the amount of inoculum present later in the season. Pruning allows air circulation which helps dry fruits after a rain event and can aid in reducing disease incidence (Ames, 2012).

On the other hand, conventional farms have a variety of fungicides that can control brown rot such as DMI fungicides, SHDI fungicides, strobilurin fungicides, and captan (Horton et al., 2005). Proper management and rotation of fungicides are important to help reduce the chance of fungicide resistance in brown rot (Horton et al., 2005). Integrating sanitation and cultural practices also important for conventional farms. Removal of other *Prunus* species in the surrounding area can help eliminate overwintering hosts for the pathogen (Adaskaveg et al., 2008).

Bacterial spot causes damage to leaves, fruits, and twigs, causing dark, cavernous lesions to appear on the fruit, which makes them unmarketable (Ritchie et al. 2008). Bacterial spot can be treated with chemicals containing copper, but it can be difficult because of the leaf sensitivity to copper toxicity (Blaauw et al., 2017).

Scab is a fungal disease that occurs in high rainfall area and lesions can be found on the twigs and leaves but are most noticeable on the fruit (Keitt, 1917). The lesions look water soaked and become bigger and darker with age, making the fruit unmarketable (Ritchie et al., 2008). Control consists of a fungicide sprays that are applied at shuck split (Ritchie et al., 2008). Anthracnose is a fungal pathogen that is seen in areas with high rainfall and temperatures. The sunken lesion created by this fungus is circular and continues expand outwards. If the fruit is cut open there is characteristic cone shape in the flesh (Adaskaveg et al., 2008).

Fruit Bagging

Fruit bagging is an agriculture practice that help produce high quality fruits and is common in countries like Japan, China, and Spain (Faci et al., 2014; Jia et al., 2005; Kitagawa et al., 1992). Fruit quality is an important aspect of production since consumers expect high quality produce. Solid soluble content (SSC), titratable acidity (TA), color, and fruit size are all testable aspects of fruit quality. Based on previous studies, data varies on whether bags have an effect on fruit quality but variance in the data could be explained because of the wide range of climates, type of bags, fruit type, and timing of bag placement (Sharma et al., 2014). All of these factors could influence one research study to be different than a previous one.

The type of bag does have an effect on certain fruit quality characteristics in peach (Kim et al., 2008). When using coated white paper bags, coated yellow paper bags, white paper bags, yellow paper bags, and newspaper bags, the newspaper bags decreased the amount of SSC in the peach fruit and had the lowest amount of light transmittance making the peach fruit less red at harvest. On the other hand, the coated white paper bags had the highest transmittance of light and therefore had the reddest peaches out of all bagged treatments. However, there was no difference in mass of the fruits (Kim et al., 2008).

A similar study was conducted on different types of peach fruit bags and how they affected fruit quality and color of the peach in Brazil (Coelho et al., 2008). In this study, the types of bags used were white bags, transparent polypropylene micro perforated bags, and milky polypropylene micro perforated bags. In this study no differences in size, mass, SSC, or TA were seen with any bagging treatment when compared to the control not bagged fruit. However, the transparent polypropylene micro perforated bags had better red coloration than the milky polypropylene and white bags. The recommendation from this study was influenced by the ability to see the fruit through the bag. Color is the main indicator if the fruit is ready to be harvested, and the ease of handling the bags and seeing the fruit was important to the local farmers. For this reason, they recommended a transparent polypropylene package for fruit bagging (Coelho et al., 2008).

An important fruit quality character of peaches is the aroma. Esters are what give peaches the fruity and floral undertones and helps develop the peach flavor. In bagged peaches the total amount of esters was significantly lower than the control non-bagged fruits (Wang et al., 2010). The decrease in the amount of esters present at ripening could have a negative effect on the taste of the fruit. Conversely, another study found no negative effect of bagging on aroma for the 'Hakuho' peach (Jia et al., 2005). Total aroma volatiles were not affected but the skin of the fruit did produce more volatiles when bagged compared to the skin of the control not bagged fruit (Jia et al., 2005). The type or color of the bag may have an influence on peach aroma; according to Li et al. (2006), 'Hujingmilu' variety of peach had the highest amount of aroma volatiles when using a single-layered orange paper bags compared to the control not bagged fruit.

Bagging of Other Fruits

Bagging has been extensively used in many other fruits and different effects on fruit quality have been found depending on the fruit. Some fruits benefit from bagging with an increase in SSC such as ‘Delicious’ variety of apples (Sharma et al., 2013) and loquats (H. Xu et al., 2010). However, other studies have concluded that bagging may not be an adequate practice for some fruits; for instance, bagging is not recommended on ‘Conference’ pear when grown in a European climate because the bags decreased the amount of sucrose and sorbitol in the fruit and decreased the color (Hudina and Stampar, 2012). A decrease in SSC is also seen in ‘Cuiguan’ and ‘Hosui’ pears (Amarante et al., 2002), Satsuma mandarins (Hiratsuka et al., 2012), and plums (Murray et al., 2005).

Size is a very important trait to growers since it is something that attracts consumers to fruit and can be evaluated visually. In bagged ‘Nam Dok Mai’ mango and longan, fruit size increased while the other fruit quality parameters stayed the same (Watanawan et al., 2007; Yang et al., 2009). When growing date palms, using a blue-colored plastic bag was shown to help increase bunch weight and improve overall fruit quality (Harshash and Al-Obeed, 2010). In contrast, bagging fruit caused a reduction in weight in ‘Conference’ pears that was so drastic that it was deemed unmarketable (Hudina and Stampar, 2012), and a decrease in size of pomegranate and loquat (Hussein et al., 1994; Xu et al., 2010). Also, certain fruit saw no significant change in fruit quality when compared to their non-bagged control, for instance bananas, carambola, and ‘Keitt’ mango fruit (Hofman et al., 1997; Muchui et al., 2017; Xu et al., 2006).

One of the main concerns for growers and homeowners when using fruit bags is how bagging affects fruit color since bags partially exclude light from reaching the fruit. Several research studies have been carried out on the effect of bags in apples. In ‘Mutsu’ apples and other varieties it was shown that an important factor for anthocyanin biosynthesis was the exposure to UV-B light (Bai et al., 2016). Specifically, allowing the fruit to receive UV-B light after unbagging and before harvest induced the fruit to produce pigmentation (Bai et al., 2016). Bagging was also shown to improve red color and could even induce apples to develop a more intense red color than control fruit if bags were removed three days before harvest in ‘Delicious’ (Sharma et al., 2013).

In red Chinese sand pears, fruit that has been bagged while maturing needed at least ten days between being unbagged and harvest to allow enough time for adequate anthocyanin production (Huang et al., 2009). Similarly, appearance was improved and less russeting was observed in ‘Cuiguan’ and ‘Hosui’ pears when bagged with brighter colors when compared to control fruit (Lin et al., 2008). Furthermore, bags have also been used to increase color uniformity. For instance, when bunches of grapes are bagged there is a more uniform coloration of the fruit. (Signes et al., 2007). The mango variety ‘Keitt’ improved uniformity of its background yellow color but saw a reduction of the characteristic red color (Hofman et al., 1997).

Bagging fruit can also help shape the physical appearance of fruit and help with controlling diseases. In nectarines, the bags decreased internal fruit quality but the bagging decreased cracking and improved overall appearance (Qin et al., 2004). Bags were also used to reduce stain or sunnyside scald in apples (Fan and Mattheis, 1998) and reduced fruit cracking in longans (Yang et al., 2009). Bananas, grown in the tropics, tend to be dirty due to the amount of dust, animals, and insects in the area. Bagging banana bunches helped make the fruit cleaner and helped reduce the incidence of bruising and making the fruit more visually appealing (Muchui et al., 2017).

Based on all these studies, results of bagging in different fruits are variable and, sometimes, contradictory depending on the abiotic and biotic factors influencing fruit production. Specifically, on peaches, research on bagging in very limited and no previous study has been conducted in the United States to determine if this could be a viable option for commercial growers. The goal of the following studies is to investigate using fruit bagging as a way to produce high quality peaches and to help farmers and backyard growers control pest and disease that can reduce yield in peach production. Studies include a commercial farm experiment and a homeowner experiment.

The objectives for the commercial farm experiment was 1) to determine if fruit bagging is a viable option for producing high quality peaches in the southeastern United States; 2) to determine if fruit bagging affects marketable yield and post-harvest disease incidence; and 3) to conduct consumer surveys using bagged fruit and to determine consumer attitude towards bagged fruit. The objective for the homeowner experiment was to 1) determine whether products available to homeowners combined with bagging would increase yield, and to 2) develop a bagging protocol that can be added to current peach tree management practices.

CHAPTER TWO

FIELD EXPERIMENT ON COMMERCIAL FARMS

Introduction

Growing peach fruit in the southeastern United States can be a challenge due to the hot and humid climate which creates high pest and disease pressure. Fruit bagging is a potential strategy to help combat pest and diseases by physically excluding them from the peach fruit. Farms using conventional methods could benefit from selling the “grown-in-bag” fruits at a premium. Organic farms could use bags as a technique to control pest and diseases which can help to increase the yield of the farm. The objective of this experiment was determine if bagging is a viable option for farmers and how the bags affected fruit quality, marketable yield and post-harvest disease incidence. Consumer surveys were also performed to determine how consumers viewed the concept of bagging.

Materials and Methods

Orchard Selection

This research was carried out in two commercial farms in South Carolina: one organic farm and one conventional farm. The organic farm was Watsonia Farms, located in Monetta, SC (33°52’09” N, 81°35’36” W). The conventional farm was Titan Farms, located in Ridge Spring, SC (33°49’27” N, 81°42’17” W). Two peach tree [*Prunus persica* (L.) Batsch] orchards were selected at each farm: one with an early-season cultivar, and another one with a mid-season cultivar. The early-season cultivar was ‘Crimson Lady’ for both farms, and the mid-season cultivars were ‘Julyprince’ and

‘Scarletprince’ (in the conventional farm the original ‘Scarletprince’ block was removed after the first year and the second year we used another block with ‘Julyprince’ trees). Trees were 7-10-year-old, grafted onto Guardian^{TM} peach seedling rootstock, at a planting density of 140 trees per acre. The soil was well-drained sandy loam at both locations.

Experimental Setup

This experiment was carried out during two years (2015 and 2016): Six trees for each cultivar were chosen and flagged. Seventy-five fruit per tree were tagged as control (non-bagged) fruit, and 100 fruit per tree were bagged. Thus, two treatments were established: control and bagged fruit. Fruit bags were obtained from Shijiazhuang City Yishun Package Product Co. Ltd. Hebei province, People’s Republic of China. The bags were customized and made of a treated (waxed) paper bag, 15 x 18 cm in size with integrated rod and notch to fit the branch. Bags did not degrade during production season. Before bagging, organic trees were treated with sulfur and pyrethroids, whereas conventional trees were treated with captan and phosmet. At harvest the fruit were collected and separated by treatments: 75 control and 100 bagged fruit per tree. Data was recorded on number of marketable (with no or minimal blemishes) and rotten/damaged fruit.

Fruit Quality

Fruit size (diameter, mm) and weight (g) were collected using a Fruit Texture Analyzer (FTA; GÜSS, Strand, South Africa) from a subsample of five fruit per treatment, per tree, per cultivar and location. Afterwards, fruit juice was squeezed from a composite sample comprised of two slices from each of the five fruit and subsequently used for measurement of SSC, pH, and TA. The SSC was measured with a temperature-compensated refractometer (model ATC-1, Atago Co., Tokyo, Japan), and data were given as °Brix. The pH and TA were determined by autotitration with 0.1 N NaOH to pH 8.2 (Titrosampler, Metrohm Riverview, FL, USA) and data were given as % malic acid per 100 g of fresh weight (FW).

Post-Harvest

Thirty fruit per tree, cultivar, and location collected at harvest were set aside for a post-harvest disease assessment. The fruit were stored in a room kept at 20 °C, and were evaluated three and seven days later to determine the incidence of brown rot.

Consumer Survey

Consumer surveys were conducted in two separate locations. The first was during the local farmer's market in Clemson, SC where 57 participants were surveyed. The second location was on Clemson University's campus within walking distance of the downtown Clemson area where 29 participates were surveyed. A table was set up with two baskets of unlabeled peaches: one basket of control (non-bagged) peaches and the other basket of previously bagged peaches. When participants approached, they were asked which batch of peaches they found more appealing. They were allowed to hold or smell the peaches. After they answered, the concept of bagging was explained to the participants and then they were asked again which batch of peaches was more appealing. Finally, they were asked if they would pay a premium for bagged peaches and how much that premium would be.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using JMP® Version 12.2.0 software (SAS Institute, Cary, NC). Percentage data was transformed using arcsine transformation formula and then was subjected to ANOVA. When a significant F-test was observed, means were separated using Tukey's test ($P \leq 0.05$).

Results

Organic Peaches

In 2015, the bagged treatment in the early-season cultivar had bigger and heavier fruit and lower TA than the control treatment (Table 2.1). However, in the early-season cultivar in 2016, there were no significant differences in fruit quality parameters between bagged fruit and the control (Table 2.1). On the other hand, the mid-season cultivar showed no significant difference in fruit quality between treatments in both years (Table 2.1). In 2015, the bagged peaches had a reduced intensity of red blush (Figure 2.3).

In both years fewer peaches were assessed to be marketable for the early-season cultivar compared to the later season cultivar, and fewer peaches were marketable in 2016 compared to 2015 (Figure 2.1). Between treatments there were significant differences that were not consistent: in 2015, there was more marketable fruit in the bagged treatment than in the control for the early-season cultivar, and in 2016 there was more marketable fruit in the bagged treatment than in the control for the late-season cultivar (Figure 2.1).

Disease pressure was high in both experimental years in the early-season cultivar. However, in 2015, bagged fruit significantly showed less (45%) disease compared to the control three days after harvest (Figure 2.2). Brown rot incidence was equally high between the two treatments after seven days in storage (Figure 2.2). The mid-season cultivar experienced less disease pressure during 2016 and both bagged and control fruit held up well in storage (Figure 2.2). There were no consistent significant differences between treatments in either year (Figure 2.2).

Conventional Peaches

Similar to the data obtained for organic trees, there was no consistent difference between bagged and control peaches with regard to fruit quality parameters (Table 2.2). The early-season cultivar showed significantly higher SSC in the control than in the bagged fruit in 2015 but had similar values in 2016 (Table 2.2). Bagged fruit showed significantly higher size and mass for early-season and mid-season cultivars during 2016 only (Table 2.2). Data is not shown for amount of marketable fruit at harvest because it was at 100% for both years in all treatments. Post-harvest data was not shown because there was no post-harvest brown rot except for the early-season cultivar in 2016 when the fruit were improperly bagged after a rain event (the fruit was still wet). Color development in conventional peaches was the same as described for organic peaches.

Consumer Surveys

Data shown are the combination of the consumer surveys taken at two locations. The data was combined because the same general trends were seen for both locations. When asked without labels which batch of peaches they found more attractive, 62% of respondents answered conventional, 23% answered they were the same, and 15% answered bagged. When the concept of bagging was explained to the consumer and then asked again which batch they found more attractive, 92% respondents answered bagged, 7% answered conventional, and 1% answered they were the same. The average increase in price the consumer is willing to pay was $0.38 per pound for bagged fruit.

Table 2.1: Fruit quality parameters for bagged and control peach fruit at the organic farm including size (circumference in cm), mass (g), SSC (degree Brix) and TA (%). Data are shown for both early season cultivar and mid-season cultivar for 2015 and 2016.

	2015				2016			
	Size	Mass	SSC	TA	Size	Mass	SSC	TA
Early Season								
Bagged	66.1a[z]	139.0a	9.1	0.7b	61.2	125.7	8.6	0.6
Control	61.3b	113.5b	9.3	0.8a	61.8	127.6	9.3	0.6
Mid-Season								
Bagged	72.1	202.9	10.2	0.9	60.2	112.3	10.7	0.8
Control	69.2	183.9	10.7	0.9	59.8	111.3	11.1	0.8

[z] Different letters within columns and for each cultivar separately indicates significant difference when comparing bagged treatment to the control for both years according to Tukey's test (P≤0.05). No letters indicate there is no significant difference between treatments.

Table 2.2: Fruit quality parameters for bagged and control peach fruit at the conventional farm including size (circumference in cm), mass (g), SSC (degree Brix) and TA (%). Data are shown for both early season cultivar and mid-season cultivar for 2015 and 2016.

	2015				2016			
	Size	Mass	SSC	TA	Size	Mass	SSC	TA
Early Season								
Bagged	59.3	108.6	7.5b[z]	0.8	66.4a	161.6a	9.9	0.6
Control	60.1	113.8	8.1a	0.8	55.0b	93.9b	9.8	0.6
Mid-Season								
Bagged	61.8	135.7	12.3	0.9	74.5a	212.8a	12.5	0.8
Control	59.7	121.4	12.2	0.9	70.9b	183.6b	12.6	0.8

[z] Different letters within columns and for each cultivar separately indicates significant difference when comparing bagged treatment to the control for both years according to Tukey's test (P≤0.05). No letters indicate there is no significant difference between treatments.

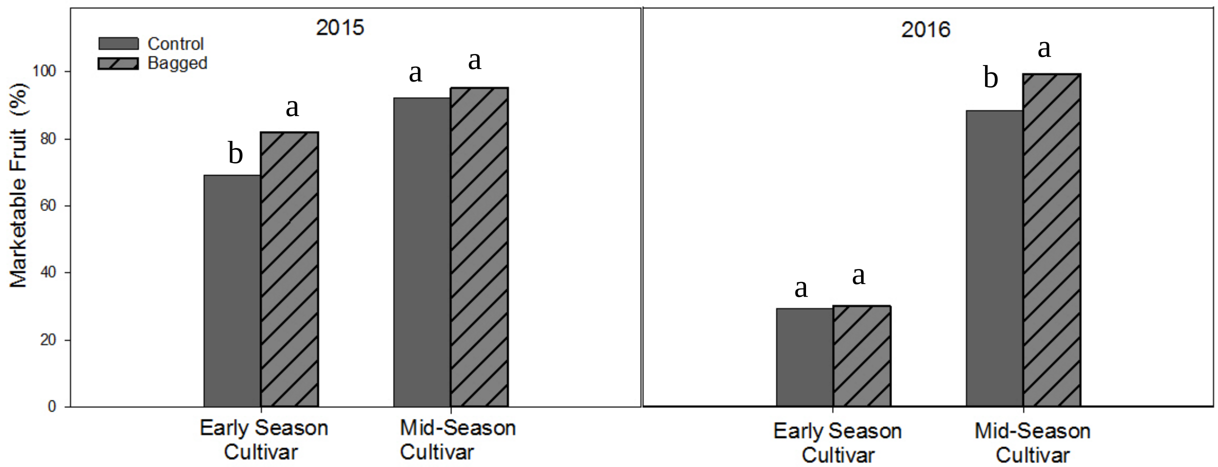

Figure 2.1: Percentage of marketable fruit from the organic farm trial for bagged and control treatments for the early- and mid-season cultivars at harvest in 2015 and 2016. Different letters indicate significant difference when comparing bagged treatment to control within each cultivar using Tukey's test (P≤0.05).

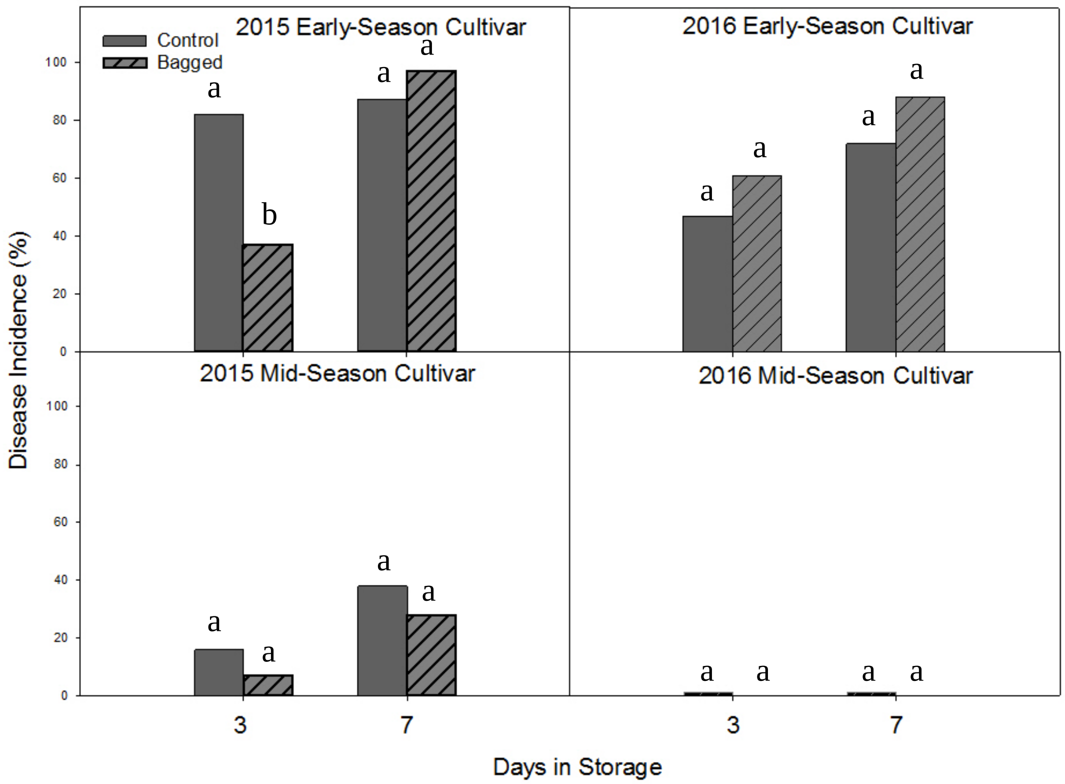

Figure 2.2: Disease incidence after three and seven days of storage at 20°C for peach fruit collected at organic farm. Evaluation at day seven includes all diseased fruit. Bagged and control treatments are shown for the early season and mid-season cultivar for 2015 and 2016. Each evaluation day was independently analyzed and means of bagged treatment and control were compared using Tukey's test (P≤0.05). Significant differences are indicated by different letters.

Control **Bagged**

Figure 2.3: Control and bagged fruit side by side to compare expression of red blush.

Discussion

Bagging did not significantly affect fruit size, mass, SSC, and TA consistently between years or location. Regarding size and mass, bagged fruit from the early season cultivar at the organic farm during 2015 and both cultivars of the conventional farm during 2016 had a larger mass and size than those grown as controls. Nevertheless, since commercial peach fruit sizing is categorical (based on diameter), these differences did not change the commercial category and therefore would not have any impact for the grower. In previous research studies on other fruits, variable responses to bagging in term of size and mass have been observed; for instance, some fruits such as date palms, mangos, longan, and carambola showed an increase in size when bagged (Harshash and Al-Obeed, 2010; Watanawan et al., 2007; Xu et al., 2006; Yang et al., 2009), but other fruits such as loquat and some 'Conference' pears showed a reduction in size (Hudina and Stampar, 2012; Xu et al., 2010). On the other hand, bagged fruit from the early-season cultivar tended to have lower SSC and TA than control fruit but significant differences were not consistent every year in both locations. In contrast to our study, there has been some instances where the SSC of peach fruit decreased in the bagged fruit vs. the control fruit (Li et al., 2001). A decrease in SSC was also observed in other bagged fruits such as pear, apple, mandarin, and plum (Chen et al., 2012; Hiratsuka et al., 2012; Lin et al., 2008; Murray et al., 2005).

Color of bagged fruit depends on factors such as time of bagging, type of bag used, and removal of bag during harvest. In this study, bagged peaches appeared to show a slight reduction in color intensity (red blush intensity), but the difference was not as drastic as reported in other fruits. For instance, apples had remarkable color reduction, especially red apples, if the bag was kept on the fruit until harvest. Interestingly, in apples, when the bag was removed three to four days before harvest the exposure to UV light gave the fruit a deeper red color (Bai et al., 2016; Fan and Mattheis, 1998; Shen et al., 2014). For this reason, double layer bags are sometimes used to help improve color while still protecting from pests and diseases, although this practice has a very high labor cost (Huang et al., 2009; Xu et al., 2010).

Regarding postharvest quality, the bags did not consistently reduce or induce the incidence of postharvest brown rot. In commercial orchards, numerous factors influence postharvest brown rot infections such as amount of rain, humidity, number of fungicide sprays, amount of inoculum present, sanitation practices, and postharvest treatments. We did not observe any post-harvest rot in bagged peaches from the conventional farm, which indicates that the fungicides applied weekly before bagging probably reduced or even nearly eliminated the inoculum surrounding the bagged peaches needed to cause infection after harvest.

Marketable yield (i.e. amount of harvested fruit without blemishes caused by pests or diseases) of bagged fruit was higher than that of control fruit in the organic setting for the early-season cultivar in 2015 and the mid-season cultivar in 2016. There was a 13% increase in marketable fruit in the early-season cultivar at the organic farm for year one. The overall decrease in yield compared to 2015 observed for the early-season cultivar for 2016 was a consequence of bagging the fruit after a rainfall. Thus, rain probably washed off the previous application of fungicide spray and there was not sufficient time for the fruit to dry out before bagging, which caused an increased number of rotten fruit inside the bags. The fruit in our study were harvested at the same time as previous years. Under different conditions ‘Wanmi’ peaches have been reported to have a harvest date around one month ahead of schedule when bags were used (Wang et al., 2010).

Bagging is a costly agricultural practice, primarily because of the labor involved during bagging and removing the bags at harvest. However, bagging may reduce some pesticide applications, and consumers may be willing to pay a premium for this type of product. The decision to use bags to help exclude pests and diseases may also be based on other factors such as pack out yield, organic certification, scale of farm, and labor availability.

In order to understand the consumer's view on this new agriculture practice, consumer surveys were conducted. Our results showed that, initially, consumers tended to prefer the deep red color of the control (not bagged) peaches, but when the concept of bagging was explained to the consumer, color was no longer the decisive factor. The majority of consumers preferred the bagged peaches because they had received less pesticides than the conventionally grown fruit and consumers were willing to pay an average of $0.38 per pound more than the current price of $1.28 per pound for conventionally produced fruit. The increase in price could help offset the cost of the bags and the extra labor involved. For instance, if a farmer harvests an average of 250 pounds of fruit per tree and sells them at a price increase of $0.38 then the potential profit per tree would be $95. In contrast, it takes about one hour for one worker to bag an entire tree and the average salary for pickers in South Carolina is about $12.00 per hour. Bags themselves would cost about $3.00 for one mature tree (400 fruit). So, at the average price increase of $0.38, the farm would have the potential to profit of up to $80.00 from bagging, but this amount could be different depending on marketing strategies and a number of intermediaries. For instance, the average increase of price per pound was highest among consumers in the survey conducted at a farmer's market, where most consumers are looking for organic products. Thus, growers may get the most benefit if this product is sold to premium markets where consumers are looking for this type of product. Profitability can also increase if the farm's marketable yield is increased. Bagging of lychee fruit in Hawaii showed positive results for farmers: when the lychee fruit were bagged, there was an increase in marketable yield from 57% to 84% and had a potential to earn $173 per tree if the fruits were bagged (Kawabata and Nakamoto, 2013).

Conventional farms may expect a different type of benefit from fruit bagging. Conventional farms already have reduced losses due to pests and diseases because of strict spray schedules, and the use of efficacious chemicals. Thus, the addition of bags is not expected to increase marketable yield in these farms. Instead these farms could use bags on certain cultivars that are susceptible to aesthetic skin problems. Cultivars with dark red blushing such as 'Sweet Dream' are more prone to show skin blemishes and this could make certain percentage of the fruit unmarketable. In this sense, the use of bags could help reduce skin disorder-related problems. Another avenue could be to market these fruit as prime fruit, for instance, "grown-in-bag" peaches. The idea of fruit bagging appeals to consumers since peaches are known as one of the most highly sprayed fruit on the market; thus, bagged peaches could be sold at a premium at some niche markets.

One of the downsides to using bags is the loss of crop if they are not utilized correctly. The bags need to be placed on the fruit when they are dry and after spraying insecticide/fungicide mixtures. If there is any moisture left on the fruit from dew or a storm event the day before and the fruit has not been sanitized, a small amount of disease inoculum can cause rot and other detrimental problems for the fruit. Training workers on how to properly secure bags onto branches is also important for the success of the bags. If tied properly the bags are able to withstand high winds and heavy thunderstorms.

Overall adding fruit bags could have numerous benefits, the most important being that the bags do not affect fruit quality but could help increase profitability if fruit is marketed at a premium. The integration of bags could also help reduce the amount of pesticides needed, which in turn may reduce costs. The “grown-in-bag” fruits are viewed positively by consumers and could potentially be sold at a higher price to help offset the price of the bags.

CHAPTER THREE

HOMEOWNERS FIELD EXPERIMENT

Introduction

Some homeowners enjoy growing and cultivating fruit trees in a backyard setting. Homeowners face some of the same pest and disease pressures as commercial farms but with less access to proper resources to combat these problems. Options available for homeowners are products that are sold at local hardware stores or over the internet since most hobbyists are not certified to spray chemical pesticides. Some homeowners are hesitant to spray any chemicals on their backyard fruit at all. Adding fruit bags to a backyard peach tree could be a method for homeowners to protect fruit from pests and diseases and to harvest more fruit. The objective for this experiment was to develop a protocol for homeowners that demonstrates how to use fruit bags on their trees and that complements current protocols for peach tree management.

Materials and Methods

Orchard Selection

The research was carried out at Clemson University's Musser Research Fruit Farm in Seneca, South Carolina (34°36'08" N, 82°52'17' W), for two years (2016 and 2017). Twelve-year old nectarine (*Prunus persica* var. nucipersica 'Juneprincess') trees were selected for this study. These trees were grafted onto Guardian^{TM} rootstock at a planting density of 5 x 7 m in loamy sand. In order to simulate tree growing conditions in a backyard, the orchard was left unsprayed (with the exception of the treatments described below) so that trees had high disease and pest pressures.

Experimental Setup

Four trees with five or more scaffold branches were selected. There were five treatments, each assigned to one of the five scaffold braches, as follows: T1 captan-malathion (Bonide Fruit Tree Spray, active ingredients: captan 11.76%, malathion 6.00%, carbaryl 0.30%. Bonide, Oriskany, NY), T2 sulfur-pyrethrins (Bonide Citrus Fruit and Nut Orchard Spray, active ingredients: sulfur 10%, pyrethrins 0.25%. Bonide, Oriskany, NY), T3 neem oil (Fungicide3, active ingredients: neem oil 0.9%. Garden Safe, Bridgeton, MO), T4 control (not sprayed) bagged, and T5 control (not sprayed) not bagged. All chemical treatments (T1 thru T3) were applied with a hand plastic mister to run off and with accordance to with the label. Captan-malathion was applied at 2.5 tablespoons per gallon. Sulfur-pyrethrins was applied at 5 fluid ounces per 1 gallon of water and neem oil came premixed and was used undiluted. Scaffold limbs were sprayed to the drip point at 100% petal fall and then every 10 to 14 days until the fruit reached golf ball size. Fifteen fruit were bagged for each treatment (T1, T2, T3, and T4) and 15 control non-bagged fruit (T5) were not bagged but tagged. The same treatments were applied to the same scaffold branches in the same trees both years.

Harvest and Post-Harvest

Each bagged fruit or tagged control fruit was picked from the tree and was either marked as ‘diseased’ or ‘not diseased’. Fruit considered ‘not diseased’ had no sign of fungal pathogen infection while ‘diseased’ fruit had disease symptoms and signs of an active fungal pathogen. All fruit showing no disease symptoms from each treatment were used for postharvest disease assessment. The fruit was placed in a room kept at 20°C and was evaluated at three days and seven days to determine the incidence of postharvest brown rot.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using JMP® Version 12.2.0 software (SAS Institute, Cary, NC). Percentage data was transformed using arcsine transformation formula and then was subjected to ANOVA. Each treatment was individually compared to the control not bagged (T5). When a significant F-test was observed, means were separated using Tukey's test ($P \leq 0.05$).

Results

At Harvest

More nectarines were recovered in 2016 than in 2017 for all treatments, including the control not bagged (T5) (Figure 3.1). In 2016, the captan-malathion treatment prior to bagging resulted in significantly greater number of nectarines without disease symptoms at harvest compared to the control not bagged treatment (T5) (Figure 3.1). In 2017, all bagging treatments performed better when compared to control not bagged, and across years there was no difference between the control bagged (T4) (Figure 3.1) treatment and all other bagging treatments according to Tukey's test ($P \leq 0.05$) (data not shown). However, treatment of captan-malathion prior to bagging resulted in significantly less rot compared to the unbagged control in both years (Figure 3.1).

Post-Harvest

In 2016, losses after three days of storage ranged from 10% to 30%. After seven days of storage, losses ranged from 37% to 56% (Figure 3.2). There were no significant differences in post-harvest brown rot between treatments for both days when compared to the control not bagged treatment. In 2017, losses after three days ranged from 32% to 54%. After seven days of storage, losses ranged from 38% to 75% (Figure 3.2). There was no control not bagged (T5) fruit at harvest so no fruit was used for post-harvest assessment.

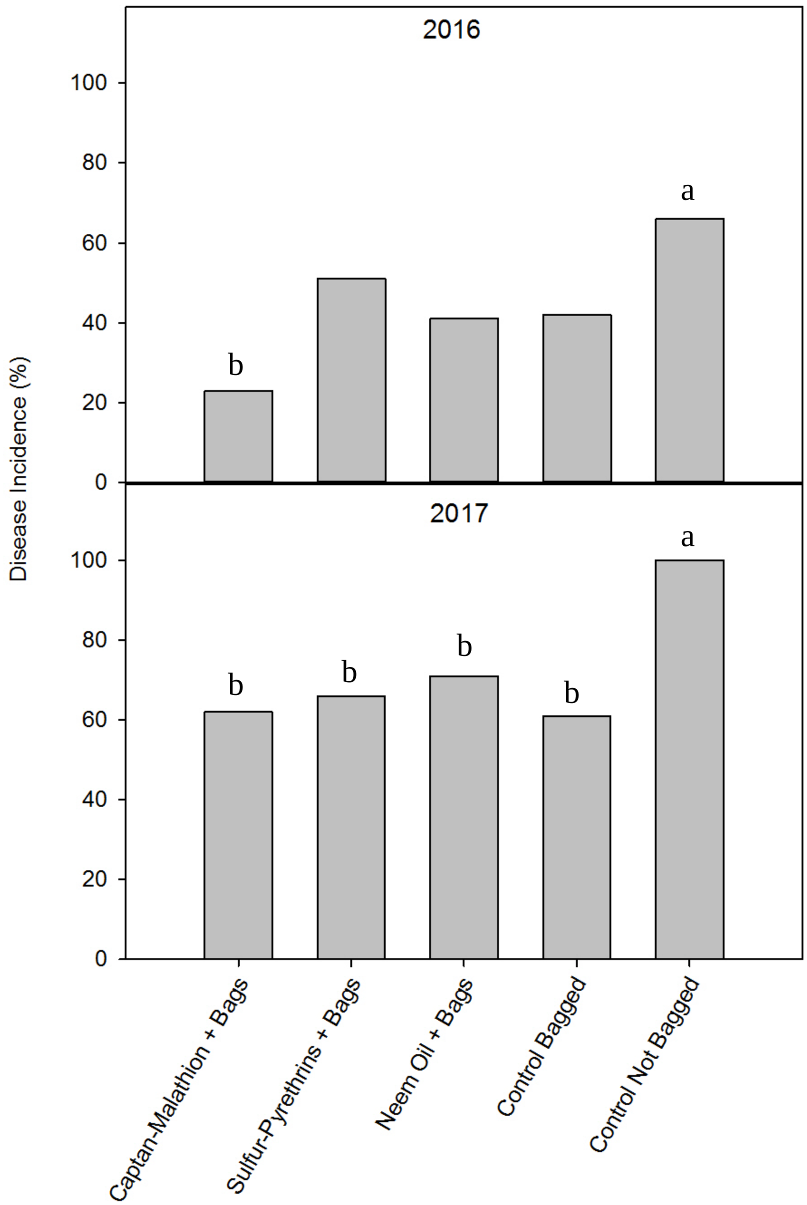

Figure 3.1: Disease incidence for nectarine fruit collected at harvest for 2016 and 2017. Each treatment was compared to the control not bagged treatment (T5) using Tukey's test ($P \leq 0.05$). Different letters indicate significant difference when comparing treatment to control not bagged (T5).

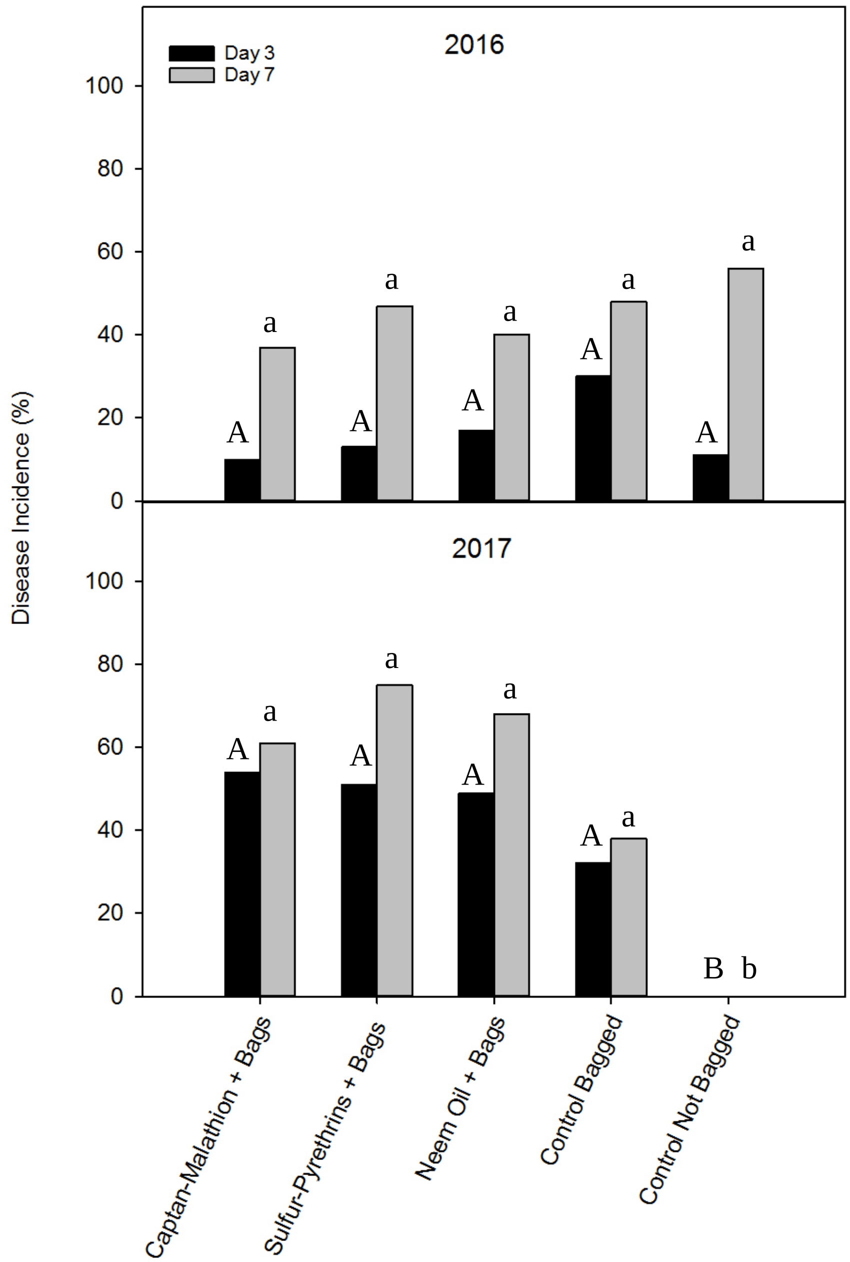
2016
Day 3
Day 7
100
80
60
40
20
0
A
a
A
a
A
a
A
a
A
a
2017
100
80
60
40
20
0
A
a
A
a
A
a
A
a
B
b
Disease Incidence (%)
Captan-Malathion + Bags
Sulfur-Pyrethrins + Bags
Neem Oil + Bags
Control Bagged
Control Not Bagged

Figure 3.2: Percentage of disease incidence after three days and seven days stored at 20°C for nectarine fruit collected for the years 2016 and 2017. Evaluation at day seven includes all diseased fruit. Each evaluation day was analyzed independently, each treatment was compared to the control not bagged using Tukey's test ($P \leq 0.05$), and significant differences are indicated by different letters. Capital letters are comparing day three values and lowercase letters are comparing day seven values.

Discussion

Homeowners and garden hobbyists grow fruits and vegetables at their home with little chemical input. Bagging of fruits is practice that can be utilized for harvesting fruit from fruit trees by organic or non-organic backyard growers. In this study, we found that bagging may in some years increase yield at harvest in nectarine trees compared to control not bagged fruit. The most consistent result was seen in the captan-malathion treatment, since it was significant when compared to the control not bagged (T5) for both years.

Fruit bagging is very popular among homeowners and commercial growers in Asia (Jia et al. 2005). In the United States there has been some interest among backyard growers of apples to reduce insect pests and detrimental diseases such as fire blight (Bessin and Hartman, 2003). Also, recommendations for using fruit bags have been made to help exclude codling moth egg and larva for damaging the apple fruit (Bush, 2014; Detweiler, 2017), but there have been no reports on using paper bags for peaches. Bagging in a homeowner or hobbyist setting is labor intensive but can be useful depending on the amount of fruit trees and maturity of the tree. Bagging peaches is an option for homeowners since economics and labor costs is not as important for homeowners as is for commercial growers (Ames, 2012; Doubrava et al., 2016).

Homeowners should follow the protocol for their region (for instance, given by Cooperative Extension services) on how to properly maintain and cultivate peach trees, and peach fruit bags can be added to complement that recommendation. The peach fruit bagging protocol recommendation to homeowners is to use a chemical pesticide to protect the fruit from pest and diseases before bagging. Starting at petal fall, the tree should be sprayed to the drip point every 10 to 14 days until the peaches reach golf ball size with chemicals such as the ones selected for this study. The most effective chemical would be something similar to Bonide Fruit Tree spray. We selected these chemicals because they are accessible for a homeowner to obtain at hardware stores and they are labeled for use on fruit trees. Then, the fruit can be thinned and bags can be placed on the fruit and left on until harvest time. If the homeowner prefers to grow without any chemical inputs, the bags are recommended to be placed when peach fruit reaches golf ball size or earlier if there is no risk of late freezes. Fruit bagging should always be done when the peaches are dry from any dew or rain to avoid fruit rotting while in the bag. The bags should be placed securely on the branch to exclude insects and prevent it from detaching during storm events.

GENERAL DISCUSSION

Bagging peaches in the southeastern United States can be a valuable practice under certain conditions. In a commercial setting, there was no consistent change in fruit quality or change in yield when the bags were utilized. In the conventional setting, if the bags were used properly there was 100% marketable yield for both bagged and control peaches. In the organic setting, the highest increase in yield was seen during 2015 for the early season cultivar which had a marketable yield increase of 13%. The real benefit from the bags might come in the form of increased profits. Consumers viewed “grown in bags” peaches in a positive light and were willing to pay a premium. A detailed economic analysis needs to be done but the increase in profits might be worth it for some farms, especially organic farms that might be struggling to find effective control methods against brown rot and plum curculio, and commercial farms that have personnel to bag the fruit and the proper marketing channels to sell this fruit at a premium.

Homeowners could benefit from using bags if they are looking for a low chemical input system. Captan-malathion products performed consistently over the two-year study and is recommended for homeowners to utilize to help protect their peaches before bagging. Fruit bags can also be utilized without adding chemical and help add an extra layer of protection to the fruit. Fruit bagging is also not limited to just peaches but has been used on most major tree fruit.

After the first year of bagging, it was observed that peaches can be successfully grown and harvested when bags are applied at an early stage of development and kept on until harvest. Thus, a trial of two acres of peach trees (bagging all the fruit on each tree) was carried out to determine the large-scale effect of bagging for one year. This trial was not part of this thesis but several observations are worth to mention. Peach fruit was not protected from a skin disorder called bronzing, which occurs on a small sections of the peach fruit skin which become discolored and bronzed, causing it to become unmarketable because of cosmetic damage. Observing bronzing on both control and bagged peaches provided clues that the cause of bronzing might be physiological instead of environmental.

Streaking is another peach skin disorder where the peach fruit have distinctive lines of discolored skin. During the bagging experiments some fruit were unbagged 10 days before harvest to see how it affected the red blush of the peaches. When the fruit were harvested we noticed that the unbagged fruit had streaking while the bagged fruit did not. The observation provided clues to the timing of streaking along with indicating it might be environmentally influenced.

Disease incidence was also observed during these bagging trails. San Jose scale was noticed in both bagged and unbagged fruit indicating that the bags do not offer protection against this insect pest. Also, when the fruit were harvested there was bacterial spot craters on both the bagged and control peaches but with one distinct difference: the control fruit had deep craters, indicating an early season infection along with small, newly formed craters indicating a later infection that had not fully developed; on the bagged peach fruit, only the deep craters were observed indicating it might be not be effective in preventing early infections of bacterial spot but could potentially reduce bacterial spot infections later in the season.

Bagging has been successful in other countries across the globe and finding the proper place for them in the United States can be a challenge. If used properly they do not affect fruit quality and does not cause the fruit to rot inside the bag. The key to using bags on a large scale is to understand the economics of each farm and see if bagging fruit would be a viable option to help increase profits. Homeowners can use bags as a practice for avoiding or reducing chemical applications in their backyard trees and being able to produce peaches and other fruits at home.

CONCLUSIONS

Commercial Farms Experiment

1. No consistent increase in marketable yield when comparing bagged fruit to control fruit for both farms over two years of study.
2. No consistent change in fruit quality parameters when comparing bagged fruit to control fruit for both farms over two years of study.
3. No significant difference in post-harvest disease incidence when comparing bagged fruit to control fruit for both farms over two years of study.

Homeowners Experiment

1. Captan-malathion was shown to significantly decrease disease incidence for both years of study when compared to control not bagged. The recommended protocol is to spray captan-malathion treatment every 10 to 14 days starting at petal fall. Bags should be placed when fruit reaches golf ball sized and kept on until harvest. This protocol should be used in conjecture with standard peach tree cultivation practices.

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