POST HARVEST CURING, STORAGE ENVIRONMENTS AND CHEMICAL TREATMENTS ON MARKETABILITY OF VIDALIA ONIONS

by

Manish Kumar Bansal

(Under the Direction of George Boyhan)

ABSTRACT

Vidalia onions are very susceptible to storage diseases. Botrytis neck rot (BNR) caused by *Botrytis allii* is most destructive. Controlled atmosphere storage (CAS) can be effective in controlling the disease. Curing before storage can also be helpful in reducing the risk of BNR. Postharvest chemical treatments can also be helpful in controlling diseases, which in turn can increase marketability. In these experiments, curing onions either in the field or with heated air helped increase marketability. Storing onions in CAS, or using Sulfur dioxide improved storability in both years of the study. Ozone improved storability in only one year. In general longer storage time decreased marketability as did increased post-storage shelf-life. Postharvest drench treatments with fungicides, Luna, Pristine, or Scholar improved storability. This was particularly evident when heat curing was not used. Use of copper based compounds Kocide or Clearblue 104 as postharvest drenches also improves storability of onions.

INDEX WORDS: *Botrytis allii,* Vidalia onion, Control atmosphere storage, Postharvest, Curing, Sulfur dioxide, Ozone, Fungicide, Short-day onions

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Manish Kumar Bansal

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By

Manish Kumar Bansal

Major Professor:	George E. Boyhan
Committee:	Daniel D. MacLean Ronald D. Gitaitis

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
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DEDICATION

I would like to dedicate this work to my mother and father for being the source of my inspiration and pride. They have always been there giving me love and support.

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TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Importance and Types of Onions

The United States is the third largest producer of dry bulb onions in the world after China and India (FAO Stat, 2010). Though onions are grown in many parts of the world, but the Vidalia sweet onions are only grown in a certain region in Georgia. The Vidalia onion industry is an important component of Georgia's agriculture and economy. In 2010, almost 13,000 acres were harvested in Georgia with a farm gate value of $139 million (Wolfe and Morgan, 2011). Onions ranked first among vegetables comprising about 18.5% of total vegetable farm gate value in Georgia (Wolfe and Morgan, 2011). "Vidalia" onions were named for the town in which they were first grown. The name 'Vidalia' is owned by the Georgia Department of Agriculture for the purposes of marketing onions. Onions called 'Vidalia onions' can only be grown in 20 specific counties in southeast Georgia. In Georgia, the Vidalia onion industry has grown rapidly in the past 25 years (Boyhan et al., 2008a). 'Vidalia' has become a brand name among sweet onions. A survey conducted by Costa et al. (2004) shows Vidalia's as the favorite sweet onions among participants. Seventy-four percent of the participants were aware of the name Vidalia and 63% of them showed their preference towards Vidalia over other sweet onions.

Based on the length of photoperiod that plants must receive to start bulbing, onions are divided into three categories: short-day, intermediate-day, and long day cultivars. Short-day plants require 11-12 hours of daylight whereas long-day onions require 14-16 hours. Intermediate- day plants will bulb when exposed to 13 hours of daylight (Brewster, 1990).

Vidalia onions, which have high water content and low total solids, fall into the short-day category. Vidalia onions possess their mild flavor due to the low amounts of sulfur compounds in the bulbs (Boyhan and Torrance, 2002). Onion pungency develops when the flavor precursor *S*-alk(e)nyl cysteine sulfoxides (ACSO)s are hydrolyzed via the enzyme allinase during maceration and bruising of the tissue (Wall and Corgan, 1992). Vidalia onions have low ACSO levels, which contribute to their mildness. Also the southeastern Georgia soils are low in sulfur content, which helps growers produce mild flavored onions that contain low levels of ACSO (Boyhan and Torrance, 2002). However, the low sulfur content makes Vidalia onions more prone to diseases and more susceptible to infection from pathogens than their sulfur containing counterparts (Boyhan, 2008).

Botrytis

There are a number of species of Botrytis which can be pathogenic to onion bulbs including *B. squamosa, B. cinerea, B. aclada, B. allii, and B. byssoidea* (Lorbeer et al., 2007). Among them, *B. allii* is the fungus that causes Botrytis neck rot. In 1917, Munn first studied and described this disease. It is an important storage disease of Vidalia onions. Farmers can face significant economic losses due to this disease. In bad years, 70% of the stored onions have been damaged by this fungus (Sanders et al., 2008).

There are a number of other factors which can influence neck rot on onions. Susceptibility of onions to infection by *B. allii* can be affected by pungency. Mild varieties of onions are more susceptible to *B. allii* than pungent varieties (Owen et al., 1950). This resistance to neck rot has been associated with the high phenol content present in colored onions (Bhattacharya and Pappelis, 1982). The rate of neck rot infection on onion bulbs increases under moist conditions (Owen et al., 1950). Sometimes, seeds infected with Botrytis can be the source of neck rot in storage (Maude and Presly, 1977; Stewart and Franicevic, 1994). *B. allii* can live in infected seed for more than 3 years when seeds were stored under 50% relative humidity at 10^{o}C (Maude, 1983). Ward (1979) found that when bulbs were stored at ambient temperature, the number of rotted bulbs increased with increasing size.

Although neck rot of onion is primarily considered a storage disease, infection starts in the field when the spores from different inoculum sources, like cull piles and infected debris, are blown into a field and settle on mature or injured leaves and necks (Jorjandi et al., 2009). Under natural conditions, the main site of infection for *B. allii* is dead or dying tissue at the neck or through an incision in the bulb (Pappelis et al., 1974). As the decay advances, the tissue will become soft with a brownish color, and in later stages the tissue loses firmness and the area around the neck will sink into the onion (Lorbeer et al., 2007). Visible symptoms of the disease, such as sunken and/or a soft neck, is often only seen after storage for 3-4 months (Stewart and Franicevic, 1994). Once harvested, onions can also be infected with BNR from contaminated bins, grading and packing lines, and storage rooms (Jorjandi et al., 2009). Maude and Presly (1977) found that in storage the fungal do not invade the sides or necks of bulbs when present on outer dry scales. These dry scales were not found to support the growth of the pathogen and that the pathogen only germinates in the presence of moisture (Jorjandi et al., 2009; Vaughan et al., 1964). Also, this dry tissue acts as a barrier for the pathogen to spread by contact (Maude, 1983).

Types and Importance of Curing.

Curing is an important postharvest treatment required to store bulbs for longer time (Maw et al., 1997a). Curing is a process intended to dry off the neck and outer scales of the bulb (Bayat et al., 2010; Maw et al., 2004). Curing is a constant process which can occur at any stage from harvest to marketing whenever the conditions around the bulb become favorable to remove moisture from the bulb (Maw et al., 2004). There are two ways of curing onion bulbs: artificial and natural. Natural curing can take place under the sun and wind after harvesting in the field. It is the least expensive way of curing and can be helpful in enhancing onion quality by allowing downward movement of nutrients from tops into the bulb (Maw et al., 1997a). Drying onions by forcing heated air around them is another way of curing called artificial curing. Standard conditions for this type of curing are blowing dry air around the onions at temperature as high as 38^{o}C with static water pressure of 1.91cm (Maw et al., 1998). Duration of heat curing varies according to the harvest maturity of the bulbs. For early harvested onions the duration of the heat curing required is more than for onions harvested at the optimal time. Onions of early maturity are benefited when the duration of heat was 72 hours, while for onions of optimal maturity required 48 hours of heat cure (Maw et al., 1997b).

Controlled Atmosphere Storage (CAS)

Storage of onion bulbs is necessary for two reasons. First, the consumer demands good quality onions year-round. Second, because onions are a biennial crop, breeders and seed companies need to store bulbs for seed production. Based on market demand, sweet onions can be stored in different ways. Onions can be sold immediately after harvest for the fresh market. For early season markets, onions can be stored for a short time with good ventilation and cold storage. Onions can be stored under refrigeration and controlled atmosphere conditions for late season sales and post-season markets (Maw et al., 1997). Storability of onions varies according to cultivar (Peters et al., 1994). There are a number of factors which affect the storage life of onion bulbs like harvest time, temperature at the time of harvest, bulb composition, number of outer skin layers, and dry matter content (Gubb and MacTavish, 2002). Water loss is also a factor affecting onion storage (Rajapakse et al., 1990). Rooting and sprouting are additional factors in storage which deteriorate the quality of onion bulbs (Adamicki and Kepka, 1974). Besides these storage limiting factors, diseases cause significant losses in storage (Ko et al., 2002). In general, long-day cultivars with high dry matter content store better than short day cultivars with low dry matter content (Gubb and MacTavish, 2002).

Successful storage of onions is possible with CAS because air inside a sealed room is replaced by a mixture of known gases at specific concentrations. Generally, the concentration of oxygen (O_2) and carbon dioxide (CO_2) used in CAS are below 8% and above 1%, respectively (Kader, 2002). The shelf life of fruits and vegetables can be increased with CAS (Saltveit, 1993). CAS is been used widely in fruits and vegetables like apples, pears, strawberries, cherries, bananas, cabbage, Chinese cabbage, etc. (Kader et al., 1989). CAS is environmentally friendly and is used in various countries to store pungent and sweet onions (Adamicki, 2005). In 1989, the Vidalia onion industry started using CAS technology (Boyhan et al., 2001). In Georgia, Vidalia onions are stored in CAS (3% O_2, 5% CO_2) at 1-2^{o}C, which helps in extending the market availability of Vidalia onions from May to September (Boyhan et al., 2008b). The Vidalia onion industry has been growing very rapidly over the past 25 years and part of this can be ascribed to CAS (Boyhan et al., 2008a).

Generally, the benefits of CAS are due to the decreased rate of respiration because the product is stored under low O_2 and increased CO_2. However, other factors like physical injuries, postharvest pathogens, and physiological disorders can shorten the postharvest life of fresh produce (Kader, 1986). CAS with 3% O_2 and 5% CO_2 results in a high percentage of high quality onion bulbs with less rooting and sprouting (Adamicki and Kepka, 1974). Quality losses are inhibited when onions are stored at 0-2^{o} C with relative humidity of 65-75 %.(Tanaka et al., 1985). CAS is helpful in inhibiting postharvest pathogens like Botrytis rot in cherries and strawberries when CO_2 is used at 10-15% (Kader, 2002). Vidalia onions had good quality after being stored for 7 months under CAS (3% O_2, 5%CO_2, and 92% N_2) at 34^{o}F and RH of 70-75% (Sumner, 2000).

Sulfur Dioxide (SO_2)

Use of SO_2 has been practiced for a long time in California to control postharvest gray mold, caused by *B. cinerea*, of table grapes (Nelson, 1985) and is still used extensively. For grape fumigation, repeated applications of SO_2 treatment are required to prevent the spread of gray mold from infected to sound berries because the initial treatment kills the fungus on the surface of the berry, but not the inoculum within the berries (Palou et al., 2002). Controlling *B. cinerea* on table grapes under commercial storage condition, SO_2 application was more effective at concentration of 200 mg/L three times a week than the standard practice of 2,500 mg/L once a week (Marois et al., 1986).

During shipment of table grapes to distant markets where SO_2 fumigation is not available to control gray mold, it has been applied as SO_2 generating pads, which produce a continuous low SO_2 concentration when incorporated sodium metabisulfite reacts with surrounding moisture (Crisosto, and Smilanick, 2004). Despite the efficacy of SO_2, berries can be injured if the rate is not controlled properly (Zoffoli et al., 2008). SO_2 technology has been tested to control brown rot in peaches (Smith, 1930), mold in raspberry (Spayd et al., 1984), and postharvest decay and peel browning in longan fruit (Wangchai et al., 2005). SO_2 has also been used to control postharvest skin browning of lychee while extending storage life (Underhill et al., 1992). Postharvest decay of green mold inoculated lemons was decreased when lemons were washed twice with water and stored for 1 week at 20^{o}C after dipping in a 2% SO_2 solution for different lengths of time (1, 5, and 10 min) at different temperatures (20, 30, 40 and 47^{o}C) (Smilanick et al.,1995). In banana, fruits were of excellent quality after storage for 6 weeks under control atmosphere and 4 weeks under regular atmosphere when treated with lower concentrations of SO_2 (2, and 8μg/kg) (Williams et al., 2003).

Ozone (O_3)

O_3 is a strong oxidizer (Ketteringham et al., 2006; Skog and Chu, 2001) and antimicrobial agent (Kim et al., 1999). O_3 is an active agent against spores of bacteria and fungi (Khadre et al., 2001). It leaves no residues on the produce as it decomposes rapidly (Guzel-Seydim et al., 2004; Palou et al., 2001). O_3 can be applied as a gas or ozonizated water for the postharvest treatment of fruits and vegetables. It can also be added continuously or intermittently in a cold storage atmosphere (Palou et al., 2001). O_3 is helpful in extending the postharvest storage life of commodities such as broccoli and cucumber (Skog and Chu, 2001).

Fungal decay in strawberries was partially controlled when they were stored for 2 days at 20^{o}C after treatment with O_3 at a concentration of 0.35 mg/L for 3 days at 2^{o}C (Perez et al., 1999). In an *in vitro* study conducted by Nadas et al. (2003), the researchers showed mycelial growth of *B. cinerea* slowed when inoculated potato dextrose agar plates were stored at 2^{o}C in an O_3 enriched (1.5 μL/L) environment. The growth rate of *B. cinerea* on carrots stored under three different temperatures (2, 8, and 16^{o}C) were reduced up to 55% when carrots were treated with gaseous O_3 at a concentration of 60μL/L. However, this effect on growth rate of *B. cinerea* was fungistatic not fungicidal, as the pathogen resumed growth when O_3 application stopped (Liew and Prange, 1994). O_3 exposure also suppressed growth of *B. cinerea* in blackberries stored at 2^{o}C for 12 days without any visual defects (Barth et al., 1995). Onions exposed to O_3 had half the mold growth compared to mold growth on untreated onions after 4 weeks of storage at low temperature. Even after 4 weeks of storage, onions stored at 20^{o}C for an additional 4 weeks still had less than 50% of the control.

Chemical Treatments

Postharvest diseases may start before or after harvesting. For a number of postharvest diseases like grey mould of grape, brown rot of peach, and yeasty rot of tomato pathogens infect crop in the field shortly before harvesting. However, symptoms of these diseases might not be visible in field. Symptoms only become visible when the pathogen grows under storage conditions. Pre- and postharvest applications of fungicides should be done to control diseases (Coates and Johnson, 1997). Postharvest application of fungicides can inhibit the activity of a number of microorganisms, which, in turn help in improving shelf-life of horticultural products (Ram et al., 2011). Presently few “reduced risk” fungicides used as postharvest treatment to control postharvest pathogens of horticultural crops have been registered in United States (Schirra et al., 2011).

Scholar is one of the fungicides registered for postharvest treatment of various diseases. The active ingredient, Fludioxonil, belongs to phenylpyrrole family. Fludioxonil is classified by the US Environmental Protection Agency as a “reduced risk” fungicide (Fenoll et al., 2009). According to Fungicide Resistance Action Committee (FRAC) classification based on mode of action of fungicide, it is classified as group 12 fungicide (Rosenberger, 2009). It has wide spectrum of disease control and is registered for postharvest use on stone fruit, pome fruit, kiwi and yam (Tedford, 2004). It is a non-systemic fungicide which inhibits the cell growth in fungus by promoting glycerol synthesis (Fenoll et al., 2009). It is compatible with chlorine and waxes that are commonly used in packing lines. Due to its long last residual and sporulation preventing activity of some pathogen it helps the fruit to store for longer period without spreading diseases in packinghouse or shipment. It's unique mode of action makes it effective in disease control even against fungal isolates that are resistant to other fungicides. In pome fruits it is more effective in controlling postharvest diseases than other registered fungicides (Tedford, 2004). In apples, it effectively controls two major pathogen *Penicillium expansum*, the cause of blue mold, and *Botrytis cinerea*, the cause of gray mold (Rosenberger, 2009). Fludioxonil is an important factor in developing pomegranate industry in California by reducing post harvest losses (Palou et al., 2007).

Pristine is a pre-harvest fungicide used to control different fungal disease in various crops like grapes, stone fruit, almonds, strawberries, onions, carrots and berries (Anonymous, 2003). It is a combination of two fungicides, pyraclostrobin and boscalid. Boscalid is a new broad-spectrum fungicide belonging to the carboxamide class, and pyraclostrobin belongs to the quinine outside inhibitor (QoI) class (Xiao and Boal, 2009). However both of these fungicides have different mode of action but they both inhibit respiration (Kim and Xiao, 2010).

Kocide (copper hydroxide) is a chemical compound which acts both as a fungicide and bactericide. It is used as a pre-harvest fungicide to prevent diseases in a number of fruits and vegetables. Copper hydroxide converts into ionic copper as the active ingredient (Anonymous, 2012). The mode of action of copper based compounds is an M according to the Fungicide Resistance Action Committee (FRAC). Fungicides with an M FRAC code have multi-site contact activity (Smith, 2012). They can denature proteins and enzymes (Babdoost, 2012). They prevent diseases as a non-systemic protectant (Petit et al., 2012). Clearblue is another copper based compound which is used to disinfect water. It is also effective against algae, fungi and bacteria (Anonymous, 2011).

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CHAPTER 2

EFFECTS OF POSTHARVEST CURING AND STORAGE ENVIRONMENTS ON MARKETABILITY OF VIDALIA ONIONS[1]

[1]Bansal, M.K., G.E. Boyhan., and D.D. MacLean. 2012. To be submitted to *HortTechnology*

Abstract

Vidalia onions are very susceptible to the storage disorder caused by Botrytis neck rot (BNR) (*Botrytis allii*). Postharvest storage methods are important to control the incidence of BNR. Controlled atmosphere storage (CAS) and curing before storage can reduce the risk of BNR. Curing can be performed either in the field or artificially using forced-air heat curing (~37°C). In other crops, such as grape and litchi, postharvest fumigation with Sulfur dioxide (SO_2) is used effectively to control BNR, while Ozone (O_3) is used as a water and surface sterilant. However little is known about the use of these fumigants in storage of Vidalia onions. Thus, the objective of this study was to evaluate these storage conditions on marketability of three Vidalia onion varieties: 'WI-129', 'Sapelo Sweet', and 'Caramelo'. All varieties were undercut, then either harvested immediately (zero cure), field cured (2 days), or forced-air heat cured (3 days at ~37°C). Bulbs were then sorted and stored in Regular air storage (RAS) (0 to 1°C, 70% R.H.), SO_2 (1000 mg/L; one time fumigation), O_3 (1 mg/L; continuous exposure), or CAS (3% O_2, 5% CO_2). After 2 and 4 months, bulbs were removed from storage, and evaluated after 1 and 14 days for quality and incidence of disorders. 'WI-129' had the lowest percent marketable onions after curing, while heat curing improved marketability in most cases. SO_2 and CAS improved storability compared to RAS. O_3 improved storability in only one year of this two year study.

Introduction

Worldwide, the United States rank third in the production of dry bulb onions after China and India (FAO Stat, 2010). The Vidalia onion industry is an important component of Georgia's agriculture and economy. In 2010, almost 13,000 acres were harvested in Georgia with an estimated farm gate value of $139 million (Wolfe and Morgan, 2011). Onions ranked first among vegetables comprising about 18.5% of total vegetable farm gate value in Georgia (Wolfe and Morgan, 2011), which makes onions the state's most important vegetable crop. Onions are divided into three categories based on the photoperiod length plants need to initiate bulbing. 1) Short-day cultivars require 11-12 hours of daylight, 2) Intermediate-day plants will bulb when exposed to 13 hours of daylight and, 3) Long-day cultivars will bulb when exposed to photoperiods for 14-16 hours (Brewster, 1990). Vidalia onions fall into the short-day category (Boyhan and Torrance, 2002).

Vidalia onions are low in sulfur compounds, which makes them mild flavored (Boyhan and Torrance, 2002). However, having the characteristic of low sulfur content makes Vidalia onions more susceptible to infection from pathogens and diseases than their sulfur containing counterparts (Maw et al., 1997b). Several fungal pathogens can attack sweet onions in Georgia. But out all of them, BNR (*Botrytis allii*) is one of the most common pathogens of sweet onion. The disease it causes is one of the most destructive diseases affecting onions in storage. In bad years, 70% of the total crop can be damaged by BNR (Sanders et al., 2008). Under natural conditions, this pathogen invades the dead or dying tissue of the onion bulb, and then grows downward through the neck into the bulbs (Pappelis et al., 1974).

The postharvest treatment required for long term storage of onions is curing (Maw et al., 1997a). Curing is a drying process intended to dry out the necks (Bayat et al., 2010) and outer scales of the bulbs (Maw et al., 2004) to prevent the loss of moisture and prevent decay during storage. From harvesting to storage, curing can occur at any stage, whenever the conditions around the bulb become favorable to remove moisture from the bulb (Maw et al., 2004). There are two ways of curing onion bulbs: artificial and natural. Natural curing can take place in the field under the sun and wind after harvest. It is the least expensive way of curing and can be helpful in enhancing onion quality by allowing downward movement of nutrients from tops into the bulb (Maw et al., 1997a). Drying onions by forcing heated air around them is another way of curing. Standard conditions for this type of curing are blowing the dry air around the onions having temperature of upto 38^{o}C with static water pressure of 1.91cm (Maw et al., 1998). Duration of heat curing varies according to the harvest maturity of the bulbs. For immature onions, the duration of heat curing required is more than for onions harvested at optimal maturity. Onions of early maturity are benefited when the duration of heat was 72 hours, while for onions of optimal maturity required only 48 hours of heat curing (Maw et al., 1997b).

Based on the market window sweet onions can be stored in different ways. 1) fresh market, where the onions are sold directly without storage, 2) early season markets, where the onions are stored in dry, well ventilated sheds, 3) mid-season markets, where onions can be stored under refrigeration. 4) late season markets, where onions can be stored in under refrigeration and CAS (Maw et al., 1997b). For successful long term storage of sweet onions, they must be kept in a dormant state. Successful storage of onions is possible with CAS. CAS has been used widely with various fruits and vegetables like apples, pears, strawberries, cherries, bananas, cabbage, Chinese cabbage, etc. (Kader et al., 1989). In Georgia, Vidalia onions are stored in CAS (3% O_2, 5%CO_2) at 1-2°C, which helps in extending the market availability of Vidalia onions from May to September (Boyhan et al., 2008b). Sumner (2000) reported good quality Vidalia onions after 7 months of storage under CAS (3% O_2, 5%CO_2, and 92% N_2) at 34°F and RH of 70-75%.

In California, SO_2 is been used for the postharvest control of gray mold of table grapes caused by *B. cinerea*, (Nelson, 1985). Marois et al. (1986) suggested that controlling gray mold on table grapes under commercial storage condition was better when SO_2 application was at a concentration of 200 mg/L applied three times a week rather than the standard practice of 2,500 mg/L once a week. SO_2 technology has been tested to control brown rot (*Monilinia fructicola*) in peaches (Smith, 1930), mold in raspberry (Spayd et al., 1984) and postharvest decay and peel browning in longan fruit (Wangchai et al., 2005).

O_3 can be helpful in postharvest treatment of fruits and vegetables. It can be applied as a gas or ozonizated water either continuously or intermittently in a CAS (Palou et al., 2001). Storage life of broccoli and cucumber can be extended with the help of O_3 (Skog and Chu, 2001). Song et al (2000) reported that onion stored at low temperature when exposed to O_3 had half of the mold growth compared to the untreated onions.

Gubb and MacTavish (2002) observed that there are a number of factors which can affect the storage life of onions. This includes harvest time, temperature at the time of harvest, bulb composition, number of outer skin layers, and dry matter content. The objective of this study was to determine the influence of varieties, curing, storage conditions, duration of storage, and post-storage shelf-life on marketability of Vidalia onions.

Materials and Methods

This two year study evaluated varieties, curing method, storage method, time in storage, and post-storage shelf-life. In the first year, three varieties, including ‘WI-129’, ‘Sapelo Sweet’, and ‘Caramelo’ were grown according to recommendations of the Georgia Cooperative Extension Service (Boyhan & Kelley, 2007) at the Vidalia Onion and Vegetable Research Center (VOVRC) in Lyons, Georgia. Harvesting began with undercutting the onions on 26 April, 10 May, and 24 May 2010 and 14 April, 21 April, and 9 May 2011, respectively for each variety. After undercutting, two-thirds of the bulbs were harvested, and transported to the Vidalia Onion Research Laboratory (VORL) in Tifton, Georgia. The remaining one-third of the undercut bulbs was permitted to field cure for 48 hours. On the same day the bulbs arrived at the VORL, they were cleaned, sorted, and graded manually to choose visually marketable onions of good size for the study. Onions with visual damage, diseases or were misshaped were discarded. Bulbs were segregated into 20 bulb lots and placed into poly mesh bags to insure good air circulation. Half the bags of each variety were then transported to Black Shank Farm in Tifton, Georgia, where they were placed inside a peanut drier for heat curing (37^{o}C) by forced air for 48 hours. While the remainder of the bags were maintained inside the VORL facility without curing.

All of the onions from the heat or field curing as well as the uncured onions were placed into one of four cold storage rooms (each having a volume of 12m^3) at 1-2°C and 70% relative humidity (RH) at the VORL. The four storage rooms were 1) Regular air storage (RAS) (20.95% O_2, 0.03% CO_2, and 78% N_2), 2) Controlled atmosphere storage (CAS) (3% O_2, 5% CO_2, and 92% N_2), 3) one-time Sulfur dioxide (SO_2) fumigation followed by RAS, or 4) continuous Ozone (O_3) under RAS. For the SO_2 fumigation treatment in 2010, 1000 gm/L of SO_2 was injected into a sealed cold storage room for one-hour, with fans running to help circulate the gas. At the completion of the fumigation, the room was vented with air for 3-4 hours until SO_2 levels were reduced below detectable levels (less than 1 gm/L). In 2011, the SO_2 treatment used 5,000 gm/L of SO_2. For the O_3 treatment, an Air-Zone XT-4000 O_3 generator (Air-Zone Inc., Suffolk, VA) was programmed to inject O_3 into the room in order to maintain a continuous exposure between 0.1 and 10 gm/L of O_3. O_3 concentration was continuously monitored using an Eco-Sensor A-21Z O_3 detector (Eco Sensors, Inc., Santa Fe, NM). Concentration of the gases, humidity and temperature were detected by sensors, which were placed inside each storage room under computer control.

Bulb samples were removed after 2 and 4 month of storage, and warmed to room temperature (22^{o}C) under controlled conditions. The following day, 4 bags (reps) of each treatment were removed randomly and weighed while a similar set of 4 bags were maintained at room temperature for 14 days to evaluate post-storage shelf-life. Bulbs were evaluated for BNR, sour skin, slippery skin, physical damage, sprouts, and other storage defects. First, bulbs were evaluated visually for any significant damage or symptoms of diseases. If there were no defects or disease symptoms observed from the outside, bulbs were then cut longitudinally to see any internal symptoms of disease. Only the bulbs passing both external and internal exams were considered marketable.

Bulbs held for 14 days under ambient conditions, were evaluated in an identical manner as described above. These same procedures were used to evaluate onions stored for 4 months. This experiment was repeated in 2011.

The experiment was arranged as a full factorial design with five factors. Three of the five factors were categorical while the remaining two was numerical. There were four replications for each combination of the five factors. The analysis was conducted by splitting the factor model into two separate analyses, one consisting of two factors and the other with three factors. Data were collected as percent unmarketable onions. This data was transformed with an arcsine square root transformation to normalize the distribution. Analysis of variance (ANOVA) was performed on transformed data. Results were back transformed to their original units. Percent marketable onion were calculated by subtracting percent unmarketable onion from hundred. Fisher's Protected Least Significant Difference at $p \leq 0.05$ was calculated.

Results

As seen in Table 1, in 2010, for all three cultivars 'Sapelo Sweet' had the greatest percent marketable onions followed by 'WI-129' and 'Caramelo'. In 2011, 'Caramelo', which had the lowest percent marketable onions in 2010 had percent marketable onions significantly higher than 'WI-129', but not 'Sapelo Sweet'. In Table 1, for 2010, storing onions without drying had lower percent marketable onions compared to heat curing, but was no different from field curing. In 2011, all three curing treatments were significantly different from each other. Field curing for 48 hours before storage had the highest percent marketable onion followed by heat curing and no curing.

Curing had significant effect on percent marketable onions (Table 2). In 2010, late harvested 'Caramelo' had significantly lower percent marketable onions with field curing. 'Sapelo Sweet' benefited most from heat curing before storage compared to field or no curing. 'WI-129' had the highest percent marketable onions both field and heat curing when compared with no curing.

In 2011, there was no difference in the curing treatments for 'Caramelo' (Table 2). Both field and heat curing resulted in greater percent marketable onions compared to no curing. Field curing had greater percent marketable onions compared to no curing for ‘WI-129’ with heat curing not differing from either field curing or no curing.

In 2010, percent marketable onions were observed highest in CAS, which was significantly greater than RAS (Table 3). O_3 and SO_2 did not, however, differ from RAS. In 2011, over all the treatment effects percent marketable onions was greatest with SO_2, followed by CAS, O_3, and RAS. Both CAS and O_3 had greater percent marketable onions compared to RAS, but were lower than the SO_2 treatment.

Storage time also had a significant effect on marketable onion. The longer the storage duration the lower the percent marketable onions. This was similar in both years of the study. Shelf-life also had a significant effect on marketable onions. In both years the percent marketable onions was significantly greater immediately after removal from storage compared to 14 days later (Table 3).

Storage duration had significant effect on marketable onion when stored in RAS, CAS, and O_3 (Table 4). There were no differences with the SO_2 treatment whether they were stored for 2 or 4 months. Percent marketable onions were significantly lower after 4 month of storage compared to 2 month of storage for RAS, CAS, or O_3 storage conditions.

Discussion

In this study the number of parameters like cultivar, postharvest curing, storage conditions, duration of storage, and shelf-life were evaluated to assess the influence on percent marketable onion. The results demonstrated clearly that postharvest curing, storage conditions, duration of storage, and shelf-life significantly affect the percent of marketable onions. This study documents that all three varieties were significantly different from each other in 2010, but in 2011 only ‘WI-129’ differed significantly from the others in terms of percent marketable onions. The early harvested cultivar WI-129 had almost the same percentage of marketable onions for both years. Past studies also support our results that early maturing varieties do not perform as well in storage as mid- and late maturing varieties (Boyhan et al., 2008b). But there were large differences in the percent marketable onions for other two cultivars. In 2010, the mid-season variety Sapelo Sweet had the highest percent marketable onions. There was a rain event in 2010 during the ‘Caramelo’ harvest, which probably contributed to the poor performance of this variety that year. However in 2011, this variety did much better comparable to ‘Sapelo Sweet’ and better than ‘WI-129’. BNR is the primary storage disease of onions in the Southeast, but infection starts in the field. Cool, moist weather conditions before or at the time of harvest favors the disease and can cause more losses in storage (Johnson, 1986). Rain events at harvest should be avoided to insure a quality product goes into storage.

Curing in general helps onions store better and for longer periods of time (Maw et al., 2005). Our study also documented that curing had a significant impact on percent marketable onions. For both years, heat curing onions benefited storage when compared to non-cured onions. Curing onions in field did not show any significant impact on percent marketable onion for 2010 which is mainly due to field cured onions of cultivar Caramelo. But in 2011, field cured onions performed best with the highest percentage of marketable onion.

Storing onions under different conditions had an impact on onion marketability. For both years storing onion under CAS conditions had more percent marketable onions. Storing onions in a SO_2 environment had the most benefit in 2011. This could be due to the higher concentration of SO_2 used in 2011 compared to 2010. In general, storing onions in CAS compared to RAS helped onions to store for a longer time. O_3 and SO_2 had more marketable onions than in RAS in 2011 only. Maclean et al., 2010 stated that when onions were stored in a SO_2 environment, they had less disease than other storage conditions. Longer storage duration decreases the marketability of onions. Similar trends were seen in our study. Storing onions for 4 months results in lower percent marketable onions compared to 2 months of storage. Similarly, longer post-storage shelf-life results in less marketable onions.

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Table 1. Percent marketable Vidalia onions of different varieties after undergoing different types of curing, 2010-11.

	2010	2011
Variety (V)	(%)	(%)
Caramelo	21.75a[z]	54.91b
Sapelo Sweet	70.41c	48.62b
WI-129	42.54b	41.13a
Curing (C)[y]		
Field	42.58a	58.54a
Heat	56.57b	49.62b
No curing	36.92a	36.24c
Probabilities		
V	0.000	0.001
C	0.000	0.000
V x C	0.000	0.000

[z]Means followed by the same letter in each column are not significantly different at $P \leq 0.05$, according to Fisher's Protected LSD.

[y]Field= Drying onions by keeping them in field for 48 hours after harvesting

Heat= Artificially drying onions in drier for 48 hours

No= Storing onion as such after harvesting without drying

Table 2. Percent marketable Vidalia onions of different varieties after undergoing different types of curing, 2010-11.

	2010			2011		
Curing[y]	Caramelo	Sapelo Sweet	WI-129	Caramelo	Sapelo Sweet	WI-129
Field	8.32a[z]	67.81a	53.33b	57.01a	64.75b	53.58b
Heat	29.48b	80.14b	55.52b	50.58a	57.40b	40.60ab
No	29.80b	61.95a	19.02a	57.05a	22.68a	29.07a

[z]Means followed by the same letter in each column are not significantly different at P≤0.05, according to Fisher's Protected LSD.
[y]Field= Drying onions by keeping them in field for 48 hours after harvesting
Heat= Artificially drying onions in drier for 48 hours
No= Storing onion as such after harvesting without drying

Table 3. Percent marketable Vidalia onions after storage under different environments for duration of 2 and 4 months with post storage evaluations at 1 and 14 days, 2010-11.

Storage room[y](R)	2010	2011
RAS	37.74a[z]	34.87a
CAS	53.59b	50.87b
O_3	46.48ab	44.35b
SO_2	43.87ab	62.25c
Storage time (T)		
2 Month	59.58a	56.49a
4 Month	30.83b	39.80b
Shelf-life (L)		
1 Day	60.13a	59.72a
14 Day	30.24b	36.34b
Probabilities		
R	0.007	0.000
T	0.000	0.000
R x T	0.010	0.000
L	0.000	0.000
R x L	0.831	0.013
T x L	0.956	0.019

[z]Means followed by the same letter in each column are not significantly different at $P \leq 0.05$, according to Fisher's Protected LSD.

[y]RAS= Storage at 1-2°C with 70% relative humidity

CAS=3% O_2, 5% CO_2, and 92% N_2 held at 1-2°C with 70% relative humidity

O_3= 0.1-10mg/L continuous exposure + RAS

SO_2= 1,000 mg/L in 2010 and 5,000 mg/L in 2011 one time injection + RAS

Table 4. Percent marketable Vidalia onions after storage under different environments for durations of 2 and 4 months, 2010-11.

	2010				2011			
	Storage conditions							
Time	RAS[y]	CAS	O_3	SO_2	RAS	CAS	O_3	SO_2
2	59.52b[z]	67.33b	60.39b	50.52a	44.01b	64.65b	59.00b	57.60a
4	16.50a	38.69a	31.99a	37.13a	25.91a	36.16a	29.25a	66.70a

[z]Means followed by the same letter in each column are not significantly different at $P \leq 0.05$, according to Fisher's Protected LSD.
[y]RAS= Storage at 1-2^{o}C with 70% relative humidity
CAS=3% O_2, 5% CO_2, and 92% N_2 held at 1-2^{o}C with 70% relative humidity
O_3= 0.1-10mg/L continuous exposure + RAS
SO_2= 1000mg/L one time injection + RAS

CHAPTER 3

EFFECT OF POST HARVEST CHEMICAL TREATMENTS ON MARKETIBILTY OF VIDALIA ONIONS[2]

[2]Bansal, M.K., G.E. Boyhan., and D.D. MacLean. 2012. To be submitted to *HortTechnology*

Abstract

Vidalia onions are very susceptible to infection from pathogens and diseases compared to other types of onions. Several fungal and bacterial pathogens can attack Vidalia onions. Botrytis neck rot (BNR), sour skin, purple blotch, pink root, and Stemphyllium leaf blight are diseases that can cause severe losses to the crop. BNR caused by *Botrytis allii* is the most common and destructive storage disease, while sour skin can cause significant losses particularly for late season varieties. The objective of this study was to see the effects of different fungicides and bactericides on marketability of Vidalia onions. Cultivar Savannah Sweet was grown, harvested and graded for good quality onions. Six different fungicide and four different bactericide treatments were applied by drenching the onion bags with one gallon of solution at the desired concentration. Onions treated with the fungicide treatments were inoculated with BNR, while the bactericide treatments were inoculated with sour skin by placing a single inoculated bulb into each bag. Half of the bags were heat cured for 48 hours and the remainders were stored immediately under refrigerated conditions at 1-2^{o}C for 2 and 4 months. Bactericide treatments were not heat cured the second year of the study. Onions were evaluated after 1 and 14 days of shelf-life. For both years all the fungicide applications were effective with greater marketable onions compared to the controls. In 2010, Scholar fungicide at the higher rate (62.1 ml/L) had the highest percentage of marketable onions. In 2011, Scholar at either rate performed similarly. Luna and Pristine fungicides were significantly better than the controls, but were similar to the low rate of Scholar. Bactericide application was also effective in reducing losses when compare with the no water control, but not to the water control.

Introduction

Worldwide, the United States ranks third in the production of dry bulb onions after China and India, with production at 3.3 million tons with a value of $701.1 million in 2010 (FAO Stat, 2010). The Vidalia onion industry is an important component of Georgia's agriculture and economy. In 2010, almost 13,000 acres were harvested in Georgia with an estimated farm gate value of $139 million (Wolfe and Morgan, 2011). In terms of revenue generated among vegetables, onions (*Allium cepa*) ranked first in Georgia with about 18.5% of total vegetable farm gate value (Wolfe and Morgan, 2011). Onions are divided into three categories based on the photoperiod length plants need to initiate bulbing. 1) Short-day cultivars require 11-12 hours of daylight , 2) Intermediate- day plants will bulb when exposed to 13 hours of daylight and, 3) Long-day cultivars will bulb when exposed to photoperiods for 14-16 hours (Brewster, 1990). Vidalia onions fall into the short-day category (Boyhan and Torrance, 2002).

Vidalia onions are low in sulfur compounds which makes them mild flavored onions (Boyhan and Torrance, 2002). However, having the characteristic of low sulfur content makes Vidalia onions more susceptible to infection from pathogens and diseases than their sulfur containing counterparts (Maw et al., 1997b). Several fungal and bacterial pathogens can attack Vidalia onions. BNR (*Botrytis allii*), purple blotch (*Alternaria porri*), pink root (*Phoma terrestris*), and stemphyllium leaf blight (*Stemphylium vesicarium*) are fungal diseases that can cause severe damage to the crop. But of all of them, BNR is the most important postharvest disease in stored onions. In bad years, 70% of the total stored crop can be damaged by BNR (Sanders et al., 2008). Under natural conditions, this pathogen invades the dead or dying tissue of the onion bulb, and then it grows downward through the neck into the bulbs (Pappelis et al., 1974).

Postharvest diseases may start before or after harvest. For a number of postharvest diseases like grey mold (*B. cinerea*) of grape (*Vitus* spp.), brown rot (*Monilinia fructicola*) of peach (*Prunus persica*), yeasty rot (*Geotrichum candidum*) of tomato (*Solanum lycopersicum*), they infect the crop in the field shortly before harvest. However, symptoms of these diseases might not be visible in the field. Symptoms may become visible when the pathogen grows under storage conditions. Pre- and postharvest applications of fungicides are used to control these diseases (Coates and Johnson, 1997). Postharvest application of fungicides can inhibit fungal activity of a number of microorganisms, which results in improved shelf-life (Ram et al., 2011). Presently few "reduced risk" fungicides used as postharvest treatments to control postharvest pathogens of horticultural crops have been registered in United States (Schirra et al., 2011).

Scholar is one of the fungicides registered for postharvest treatment of various diseases. The active ingredient, Fludioxonil, belongs to the phenylpyrrole family. Fludioxonil is classified by the US Environmental Protection Agency as a "reduced risk" fungicide (Fenoll et al., 2009). According to the Fungicide Resistance Action Committee (FRAC) classification based on mode of action, it is classified as a group 12 fungicide (Rosenberger, 2009). It has a wide spectrum of activity and is registered for postharvest use on stone fruits (*Prunus spp.*), pome fruits (*Malus domestica* and *Pyrus communis*), kiwi (*Actinidia deliciosa*) and yam (*Diosorea spp.*) (Tedford, 2004). It is a non-systemic fungicide which inhibits the cell growth of fungi by promoting inhibiting osmotic signal transduction (Fenoll et al., 2009). It is compatible with chlorine and waxes that are commonly used in packing lines. Due to its long residual and ability to inhibit sporulation, it helps to store fruit for longer periods without spreading diseases in the packinghouse or during shipment. It's a unique mode of action makes it effective in disease control even against the fungal isolates that are resistant to other fungicides. In pome fruits it is more effective in controlling postharvest diseases than other registered fungicides (Tedford, 2004). In apples (*M. domestica*), it effectively controls two major pathogens *Penicillium expansum*, the cause of blue mold, and *B. cinerea*, the cause of gray mold (Rosenberger, 2009). Fludioxonil has been an important material in developing the pomegranate (*Punica granatum*) industry in California by reducing postharvest losses (Palou et al., 2007).

Pristine is a pre-harvest fungicide used to control different fungal diseases in various crops like grapes, stone fruit, almonds (*P. dulcis*), strawberries (*Fragaria x ananassa*), onions, carrots (*Daucus carota subsp. sativus*) and berries (*Rubus spp.*) (Anonymous, 2003). It is a combination of two fungicides, pyraclostrobin and boscalid. Boscalid is a new broad-spectrum fungicide belonging to the carboxamide class, and pyraclostrobin belongs to the quinine outside inhibitor (QoI) class (Xiao and Boal, 2009). These fungicides have different modes of action, but they both inhibit respiration (Kim and Xiao, 2010).

Kocide (copper hydroxide) is a chemical compound which acts both as a fungicide and bactericide. It is used as a pre-harvest fungicide to prevent diseases in a number of fruits and vegetables. Copper hydroxide converts into ionic copper as the active ingredient (Anonymous, 2012). The mode of action of copper based compounds is an M according to the Fungicide Resistance Action Committee (FRAC). Fungicides with an M FRAC code have multi-site contact activity (Smith, 2012). They can denature proteins and enzymes (Babdoost, 2012). They prevent diseases as a non-systemic protectant (Petit et al., 2012). Clearblue is another copper based compound which is used to disinfect water. It is also effective against algae, fungi and bacteria (Anonymous, 2011).

Another important postharvest treatment required for long term storage of onion bulbs is curing (Maw et al., 1997a). Curing is a drying process intended to dry down the necks (Bayat et al., 2010) and outer scales of the bulbs (Maw et al., 2004) to prevent the loss of moisture and the attack by decay during storage. From harvesting to storage, curing can occur at any stage, whenever the conditions around the bulb become favorable to remove moisture from the bulb (Maw et al., 2004). There are two ways of curing onion bulbs: artificial and natural. Naturally curing takes place under the sun and wind after the harvest when bulbs are left in the field. It is the least expensive way of curing and can be helpful in enhancing onion quality by allowing downward movement of nutrients from tops into the bulb (Maw et al., 1997a). Drying onions by forcing heated air around the bulbs is another way of curing. Standard conditions for this type of curing are blowing the dry air around the onions having temperature of upto 38^{o}C with static water pressure of 1.91cm (Maw et al., 1998). The duration of heat curing varies according to the harvest maturity of the bulbs. For early harvested onions, the duration of heat curing required is more than for onions harvested at the optimal time. Early harvested onions are benefited when the duration of heat curing was 72 hours, while for onions of optimal maturity required only 48 hours of heat curing (Maw et al., 1997b).

The objective of this study was to evaluate postharvest treatments, time in storage, and post-storage shelf-life on marketability of Vidalia onions.

Materials and Methods

This two year study evaluated postharvest treatments, time in storage, and post-storage shelf-life. In the first year, cultivar Savannah Sweet was grown according to recommendations of the Georgia Cooperative Extension Service (Boyhan et al., 2001) at the Vidalia Onion and Vegetable Research Center (VOVRC) in Lyons, Georgia. Harvesting began with undercutting on

10 May 2010. After harvest, bulbs were transported to the Vidalia Onion Research Laboratory (VORL) in Tifton, GA. On the same day, the bulbs arrived at the VORL, they were cleaned, sorted, and graded manually to choose visually marketable onions of good size for the study. Onions with visual damage, diseases or misshaped bulbs were discarded. Bulbs were segregated into 20 bulb lots and placed into poly mesh bags to insure good air circulation.

Nine treatments including both fungicides and a bactericide were used in the study. In 2010, the fungicides used in this study were 1) Luna (1.3 ml/L), 2) Pristine (35.7 ml/L), and 3) Scholar (30.9 ml/L and 62.1 ml/L) at two rates. Also included were a water only control, and a no water control. The bactericide evaluated was Kocide (1.2 gm/L) with a water only control and a no water control. In 2011, one more bactericide treatment, Clearblue (3 ml/L) was added to the experiment.

To apply the treatments, solutions of the desired concentration were made with tap water. Then the 20 bulb bags were placed into a 117 L polyethylene container (Rubbermaid, Huntersville, NC) and 1 gallon of the drench solution was poured twice over the onion bulbs (bags were turned over between applications). After application of the fungicide treatments including the controls, a single bulb inoculated with BNR was placed into each bag of treated onions. In the same manner, after application of the bactericides, a single bulb inoculated with sour skin (*Pseudomonas (Burkholderia) cepacia*) was placed into the bags prior to curing or storage. After drenching, half the treated bags treated were transported to the Black Shank Farm in Tifton, Georgia, where they were placed inside a peanut drier for heat curing (37^{o}C) by forced air for 48 hours. While the remainder of the bags were maintained inside the VORL facility without heat treatment and were placed into refrigerated storage at a temperature of 1-2^{o}C and ≥80% relative humidity.

After 48 hours, the heat cured bulbs were removed from the peanut dryer and transported to the VORL where they were placed in refrigerated storage with the uncured onions.

Bulb samples were removed after 2 and 4 months of storage, and warmed to room temperature (22^{o}C) under controlled conditions. The following day, 4 bags of each treatment were removed randomly and weighed while a similar set of 4 bags were maintained at room temperature for 14 days before evaluation.

Bulbs were evaluated for BNR, sour skin, slippery skin (*Burkholderia gladioli pv. Alliicola*), physical damage, sprouts, and other storage defects. First, bulbs were evaluated visually for any significant damage or symptoms of diseases. Bulbs were then cut longitudinally to see any internal symptoms of disease. Only the bulbs passing both external and internal exams were considered marketable.

Bulbs held for 14 days under ambient conditions, were evaluated in an identical manner as described above. These same procedures were used to evaluate onions stored for 4 months.

The experiment was designed with a full factorial arrangement. There were four replications for each combination of factors. Analysis was done separately for the fungicide and bactericide treatments. Data were collected as percent unmarketable onions. Data were transformed with the arcsine square root transformation to normalize the distribution. Analysis of variance (ANOVA) was performed on transformed data. Results were back transformed to their original units of percent unmarketable onions. Percent marketable onions were calculated by subtracting percent unmarketable onion from 100. Fisher's Protected Least Significant Difference at $p \leq 0.05$ was then calculated.

Results

As seen in table 5, all the fungicide applications were effective with percent marketable onions greater when compared to the water and no water controls. The water control also had significantly greater marketable onions compared to the no water control. In both years, Scholar used at the higher rate had greater percent marketable onions compared to the controls. In 2010, Scholar at the high rate was significantly better than Scholar at the low rate. In addition, Scholar at the high rate did not differ from Luna. In 2011, Scholar used at the high rate had significantly greater percent marketable onions compared to the controls and Pristine. The high rate of Scholar did not differ from the low rate of Scholar or Luna for percent marketable onions.

Curing had greater marketable onions in 2010, compared to uncured onions, but there was no difference between cured and uncured onions in 2011. Onions stored for 2 months in 2010 had greater percent marketable onions compared to onions stored for 4 months. There was no difference in percent marketable onions after 2 or 4 months of storage in 2011. Onions kept for 14 days under ambient conditions, after removal from storage, had lower percent marketable onions when compared with onions evaluated one day after removal from storage.

The fungicide treatments were significantly different from the no water control after 2 and 4 month of storage (Table 6). After 2 months of storage, only Scholar at the high rate had significantly greater percent marketable onions compared to both the water and no water controls. After 4 months, Scholar at both the low and high rates had significantly greater marketable onions compared to the water and no water controls.

Curing affects the fungicide treatments with percent marketability of onions. All the fungicide treatments that were not cured were significantly different from both controls (Table 7). Only Scholar at either rate was significantly different from the no water control with heat curing. Whether the onions were cured or not the post-storage percent marketable onions were greater immediately after removal from storage compared to 14 days after removal.

The treatment effects for percent marketable onions differ based on post-storage shelf-life in 2010 (Table 8). Immediately after removal from storage Luna and Scholar at the high rate had the greatest percent marketable onions compared to the no water control. Fourteen days after removal from storage, all the fungicide treatments had greater percent marketable onions compared to either water or no water control. Heat curing had no effect either 1 or 14 days post-storage. Immediately after removal from storage, onions stored for 2 months had more marketable onions compared to onions removed after 4 months. This was not the case, however, 14 days post-storage.

Curing did not affect the percent marketable onions among any of the fungicide treatments with the exception of Pristine in 2011 (Table 9). Shelf-life affected all the treatments on onion marketability. After 14 days post-storage, the percent marketable onions was less compared with onions evaluated immediately after removal from storage.

Onions treated with bactericide Kocide had significantly more marketable onions when compared with the no water control in 2010 (Table 10). Heat curing had significantly more marketable onions compared to uncured onions. Storage time and shelf-life affected the percent marketable onions in a similar way. Storing onion for 2 months had higher marketable onions compare to storing them for 4 months. Similarly, onions 14 days post-storage under ambient conditions had lower percent of marketable onions compared to onions evaluated immediately after removal.

Heat curing does not improve onion marketability immediately after removal from storage, but it helps in improving marketability if onions were held for 14 day post-storage

(Table 11). There were more marketable onions 2 months after removal when evaluated immediately compared to after 4 months of storage. There was no difference in storage time after 14 days post-storage.

Heat cured onions did not show significant differences for percent marketable onions between 2 and 4 month of storage in 2010 (Table 12). Without heat curing onions stored for 2 months had significantly more marketable onions than those stored for 4 months.

Onions treated with the bactericide Kocide or Clearblue had significantly more marketable onions compared to the no water control in 2011 (Table 13). There were no differences between the bactericide treatments and the water control. Onions stored for 4 months in 2011 had more marketable onions compared to onions stored for only 2 months. Onions evaluated 14 days after removal from storage had significantly fewer percent marketable onions compared to onions evaluated immediately after removal in 2011.

Discussion

In this study, the parameters evaluated included postharvest chemical treatments, postharvest curing, storage duration, and shelf-life. The results demonstrated clearly that all parameters significantly affected the percent marketable onions in 2010. In 2011, only postharvest treatments and shelf-life significantly affect the marketability of onions. In both years, all the fungicide treatments were significantly effective in increasing marketability of onions when compare with both water and no water controls. To our surprise, treating onions with water also showed positive results when compared with no water. Water in both years, significantly increased the marketability of onions compared to no water. It is unclear what occurred, but water may have washed inoculum from bulb surfaces. However, heat treatment eliminated the significant differences between fungicide treatments and the water treatment in both years. It could be possible that the heat treatment masked the effects of the fungicides or these fungicides don't show any residual activity after undergoing heat treatment. Treated onions that were stored immediately into cold storage were significantly different among the fungicide treatments and including both the water and no water controls. Heat curing was better than no curing in 2010, but there was no significant difference for 2011. Similarly, 2 months of storage had better percent marketable onions then 4 months, but only in 2010 not 2011. As expected, the 1 and 14-day post-storage simulated marketing period showed that the percentage of marketable onion was lower over time. There was no significant difference between fungicides and water treatment after 1 day post storage in 2010. But there was big difference between onions treated with fungicides compare to the water and no water controls after 14 days post storage. This indicates that fungicides are still having some residual activity in disease control.

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Table 5. Percent marketable Vidalia onion after treated with different fungicide, curing, storage time, and shelf-life for the year 2010-11.

Treatment	Application rate	2010	2011
Luna	1.3 ml/L	79.7de[z]	78.8cd
Pristine	35.7 ml/L	73.1c	74.3c
Scholar	30.9 ml/L	75.6cd	80.2cd
Scholar	62.1 ml/L	82.1e	83.2d
Water		61.3b	64.2b
Control		49.1a	44.7a
Curing			
Heat		73.4b	71.1a
No heat		68.3a	72.8a
Storage time			
2 Month		75.0b	71.9a
4 Month		66.6a	72.1a
Shelf-life			
1 Day		79.5b	86.1b
14 Day		61.0a	57.0a
Probabilities			
Treatment		0.000	0.000
Curing		0.011	0.607
Treatment x Curing		0.000	0.009
Storage time		0.000	0.448
Treatment x Storage time		0.033	0.523
Curing x Storage time		0.270	0.371
Treatment x Curing x Storage time		0.101	0.275
Shelf-life		0.000	0.000
Treatment x Shelf-life		0.000	0.000
Curing x Shelf-life		0.017	0.521
Treatment x Curing x Shelf-life		0.021	0.284
Storage time x Shelf-life		0.000	0.000
Treatment x Storage time x Shelf-life		0.955	0.000
Curing x Storage time x Shelf-life		0.602	0.651
Treatment x Curing x Storage time x Shelf-life		0.069	0.003

[z]Means followed by the same letter in each column are not significantly different at $P \leq 0.05$, according to Fisher's Protected LSD.

Table 6. Percent marketable Vidalia onions for pre-storage treatments and post-storage shelf-life after 2 and 4 months of refrigerated storage for the year 2010.

Treatment	2 Month	4 Month
Luna (1.3 ml/L)	80.8bc[z]	78.5bc
Pristine (35.7 ml/L)	73.8bc	72.4bc
Scholar (30.9 ml/L)	78.3bc	72.7c
Scholar (62.1 ml/L)	84.1c	79.9c
Water control	69.7ab	52.7ab
No water control	60.2a	37.4a
Shelf-life		
1 Day	85.8b	72.2b
14 Day	61.5a	60.5a

[z]Means followed by the same letter in each column are not significantly different at $P \leq 0.05$, according to Fisher's Protected LSD.

Table 7. Percent marketable Vidalia onion with pre-storage treatments and post-storage shelf-life with and without heat curing for the year 2010.

Treatment	Heat	No Heat
Luna (1.3 ml/L)	75.5ab[z]	83.4b
Pristine (35.7 ml/L)	66.5a	79.5b
Scholar (30.9 ml/L)	79.6b	71.2b
Scholar (62.1 ml/L)	80.2b	83.8b
Water control	71.7ab	50.5a
No water control	65.3a	31.7a
Shelf-life		
1 Day	79.9b	79.2b
14 Day	66.2a	55.6a

[z]Means followed by the same letter in each column are not significantly different at $P \leq 0.05$, according to Fisher's Protected LSD.

Table 8. Percent marketable Vidalia onion for pre-storage treatments, curing, and storage time 1 and 14 days post-storage for the year 2010.

Treatment	1 Day	14 Day
Luna (1.3 ml/L)	83.2b[z]	75.8c
Pristine (35.7 ml/L)	81.6ab	64.0c
Scholar (30.9 ml/L)	77.7ab	73.3c
Scholar (62.1 ml/L)	85.1b	78.7c
Water control	75.6ab	43.7b
No water control	73.1a	22.7a
Curing		
Heat	79.9a	66.2a
No heat	79.2a	55.6a
Storage time		
2 Month	85.8b	61.5a
4 Month	72.2a	60.5a

[z]Means followed by the same letter in each column are not significantly different at P≤0.05, according to Fisher's Protected LSD.

Table 9. Percent marketable Vidalia onion with and without curing and post-storage shelf-life for the fungicide treatments, for the year 2011.

Curing	Luna	Control	Pristine	Scholar	Scholar	Water
Heat	73.4a[z]	45.5a	67.8a	77.4a	86.0a	72.5a
No heat	83.3a	43.6a	79.8b	82.8a	80.0a	53.7a
Shelf-life						
1 Day	91.6b	82.3b	83.7b	85.8b	87.8b	86.8b
14 Day	69.8a	11.2a	63.8a	73.7a	77.8a	42.1a

[z]Means followed by the same letter in each column are not significantly different at $P \leq 0.05$, according to Fisher's Protected LSD.

Table 10. Percent marketable Vidalia onions after cold storage when treated with Kocide and water and no water controls curing, storage time, and post-storage shelf-life for the year 2010.

Treatment	Application rate	% Marketable onion
Kocide	1.2 g/L	62.8b[z]
Water		58.8ab
No water		54.3a
Curing		
Heat[y]		68.9b
No heat[x]		47.5a
Storage time		
2 Month		67.0b
4 Month		49.8a
Shelf-life		
1 Day		73.7b
14 Day		41.7a
Probabilities		
Treatment		0.121
Curing		0.000
Storage time		0.000
Shelf-life		0.000
Treatment x Curing		0.514
Treatment x Storage time		0.434
Curing x Storage time		0.035
Treatment x Curing x Storage time		0.380
Treatment x Shelf-life		0.194
Curing x Shelf-life		0.000
Treatment x Curing x Shelf-life		0.240
Storage time x Shelf-life		0.000
Treatment x Storage time x Shelf-life		0.463
Curing x Storage time x Shelf-life		0.470
Treatment x Curing x Storage time x Shelf-life		0.144

[z]Means followed by the same letter in each column are not significantly different at $P \leq 0.05$, according to Fisher's Protected LSD.

[y]Onions dried artificially by warm air for 48 hours after given treatment

[x]Onions stored directly into cold room after given treatment

Table 11. Percent marketable Vidalia onions 1 and 14 days post-storage with and without curing and 2 and 4 months after removal from storage for the year 2010.

Curing	1 Day	14 Day
Heat	77.2a[z]	59.7b
No heat	69.9a	23.5a
Storage time		
2 Month	85.5b	43.0a
4 Month	58.9a	40.4a

[z]Means followed by the same letter in each column are not significantly different at P≤0.05, according to Fisher's Protected LSD.

Table 12. Percent marketable Vidalia onions after storage for 2 and 4 months with and without heat curing for the year 2010.

Storage time	Heat	No heat
2 Month	73.3a[z]	60.1a
4 Month	64.3a	34.4b

[z]Means followed by the same letter in each column are not significantly different at $P \leq 0.05$, according to Fisher's Protected LSD.

Table 13. Percent marketable Vidalia onions after treatment with Clearblue and Kocide storaged for 2 and 4 months and evaluated post-storage immediately after removal and 14 days later for the year 2011.

Treatment	Application rate	% Marketable onion
Clearblue	3 ml/L	47.4b[z]
Kocide	1.2 g/L	52.5b
Water control		53.3b
No water control		21.3a
Storage time		
2 Month		33.0a
4 Month		54.1b
Shelf-life		
1 Day		72.0b
14 Day		14.2a
Probabilities		
Treatment		0.000
Storage time		0.000
Shelf-life		0.000
Treatment x Storage time		0.001
Treatment x Shelf-life		0.000
Storage time x Shelf-life		0.000
Treatment x Storage time x Shelf-life		0.094

[z]Means followed by the same letter in each column are not significantly different at $P \leq 0.05$, according to Fisher's Protected LSD.

CHAPTER 4

CONCLUSIONS

In the first study, we evaluated different storage conditions on marketability of Vidalia onions. Results from both years in this study indicated that controlled atmosphere storage (CAS) is better than RAS. However, the results from the second year indicated that adding SO_2 at higher concentrations in addition to RAS can be more beneficial than RAS alone. However, exposure to SO_2 at high rates can damage some varieties of onion. This was particularly evident with ‘Caramelo’. Finally, curing, in general, helps improve onion storability.

In the second study, we evaluated postharvest applications of different fungicides and bactericides on marketability of Vidalia onions. Results from both years showed that fungicide applications can be helpful in increasing the percent marketable onions when compared to untreated onions. Treating onions just with water also increased percent marketable onions compared to untreated onions.

Treating onions with a bactericide can also increase marketability compared to the no water control. However, treating onions with bactericides did not significantly differ from the water control.