ABSTRACT

MONTERO DE ESPINOSA BASELGA, FERNANDO. Effects of Preharvest and Postharvest Treatments on Incidence and Severity of Internal Necrosis in ‘Covington’. (Under the direction of Dr. Jonathan Schultheis).

In study 1, three replicated field locations in 2016 and two in 2017 were conducted to evaluate several preharvest and postharvest treatments and how those affected occurrence of Internal Necrosis (IN) of the sweetpotato cultivar ‘Covington’. Four preharvest treatment combinations were evaluated with the application of a high chlorine versus minimal chlorine fertilizers and mowing versus not mowing prior to harvest. For the postharvest treatments, 30 roots were obtained from each preharvest plot and placed in 75ºF and 85ºF rooms in 2016 and 2017, with the addition of a 95ºF room in 2017. Roots were immediately stored in these rooms for duration after harvest of ½, 1, 2, 3 & 5 weeks in 2016, and ½ ,1 & 2 weeks in 2017, Shorter durations (1/2- and 1-week) coincided with industry recommendations while longer durations mimicked the challenges that some commercial facilities have to cool down the temperatures of rooms after curing. Once temperature and duration treatments were completed, roots were placed in a 58ºF storage room until cut. A control treatment was included where roots were not cured and placed immediately after harvest in a 58ºF storage room. Samples were cut 49 to 80 days after harvest and incidence and severity of IN were recorded. Preharvest fertilizer treatments had minimal effect on the occurrence of IN while mowing prior to harvest in most studies reduced IN incidence when roots were placed in storage for more than ½ week and exposed to temperatures of at least 75ºF. Postharvest treatments significantly impacted IN occurrence and severity, with lower temperatures (75ºF vs 85ºF) and shorter durations (½ versus 1, 2, 3 or 5 weeks) significantly reducing IN occurrence in ‘Covington’ sweetpotato.

In study 2, two studies were conducted in 2016 and 2017 to evaluate the pre-harvest and postharvest practices of six North Carolina sweetpotato commercial growers and link the conditions encountered to the occurrence of IN in the sweetpotato cultivar Covington. Bins of sweetpotatoes were collected from each grower´s field the same day, then redistributed the following day so that each storage facility received a bin from each grower (6 total). This process included one harvest in 2016 and three harvests in 2017. Each harvest served as a replication. Temperature and relative humidity (RH) data were recorded from harvest until the last 30-root sample (4 total) was cut from each of the six bins at each location and the incidence of IN was recorded. Facility conditions were more important than grower practice both years. The effects of temperature and RH in, the storage rooms over various time periods (01-07, 01-14, 01-30 and 14-28 days after harvest, DAH) on IN occurrence were evaluated using Pearson correlation analysis. Maximum, minimum and average temperatures for 01-07 and 01-14 DAH had significant R-values greater than 0.6 in 2016, and between 0.1 and 0.3 in the 2016/2017 combined study. These temperature variables were correlated with IN occurrence during the first two weeks after harvest in storage. Relative humidity had little or no correlation with IN occurrence. Of the factors tested, temperature conditions during storage the first two weeks after harvest appear to be highly influenced in subsequent IN incidence. Additional storage studies and modeling is warranted, especially temperature, to better predict IN occurrence.

Effects of Preharvest and Postharvest Treatments on Incidence and Severity of Internal Necrosis in 'Covington'

By
Fernando Montero de Espinosa Baselga

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

Horticultural Science

Raleigh, North Carolina

2019

APPROVED BY:

Michael D. Boyette

L.M. Quesada-Ocampo

Jonathan R. Schultheis
Chair of Advisory Committee

DEDICATION

My dedication goes to my dear mom and dad. Thanks for the efforts that both of you have made to send me overseas to pursue my dreams. Thanks for the education you gave me based on the strong values of respect, humbleness, passion and sacrifice. I strongly believe these values have helped me to achieve my goals in life and helped me to become a better person.

Although I didn´t spend much time with them since they left this world too early, I dedicate this thesis to my grandparents. Both dedicated most of their life to agriculture and supported the rural world as a researcher and as a farmer. They worked hard for the farmer´s rights during rough times when Spain most needed it after the Civil War. I am sure they would have enjoyed my research and they would have given me lots of good advice.

BIOGRAPHY

Fernando was born December 28, 1992 to Fernando Montero de Espinosa and Begoña Baselga. Fernando was born and raised in a small city in the southwest of Spain, Badajoz, and has two sisters, Maria born in 1994 and Begoña born in 2002. Surrounded always by family, he followed his grandparents and uncle vocation in agriculture and he started his bachelor’s degree in the University of Extremadura, Spain in the Department of Agronomic Engineering with a major in Food Processing Industries and minor in Vegetable Production. During his junior year (2014) he was awarded a scholarship to attend a year at the University of Lisbon, in the Instituto Superior de Agronomia. While there he was exposed to a more diverse and international student environment and participated on research programs in the food science and processing department. After his final semester of undergraduate, several internship opportunities in his home town; CONESA and AGRAZ, processing tomato industries supplying final product for Heinz, and the other abroad; at NC State University, Food Science Department. Both this opportunities gave him a better idea of what he liked in the field of agriculture and what his next steps would be. In August of 2016 Fernando started his Master of Science in the Department of Horticultural Science. With the guidance of Dr. Jonathan Schultheis, he completed two years and a half of research on a project that involved preharvest and postharvest factors of the sweetpotato production. Also, he closely collaborated in many other studies on cucurbits such as variety trials.

ACKNOWLEDGEMENTS

I thank my advisor Dr. Jonathan Schultheis and Keith Stark, Research Associate. They have showed me that hard work and small details in research makes the difference between getting the work done or having a great work done “you are only as good as your last study”. They have supported me throughout these two and a half years and worked very hard and patiently to help me achieve this degree.

I thank my committee members, Dr. Lina Quesada and her technicians for sharing with me all their experience in postharvest diseases and helping me to improve my knowledge in this field and Dr. Mike Boyette for sharing his broad experience in the sweetpotato postharvest field and giving me the opportunity to work with the sweetpotato industry.

A sincere thank you to our summer help; Chandler Fulmer, Marlee Trandel, Libby Indermaur, Shannon Dexter, Benn Indermaur, and Stephen Bajorek, I could not have finished any of my work without them. Thanks for the great job done, for the long hours under the summer heat and humidity and long hours driving after twelve-hour days. You made the time go by faster.

A big thank you to the research station´s personnel at Cunningham Research Station in Kinston; Chris Lee and his workers, and the Horticultural Research Crops Station in Clinton; Rodney Mozingo, Wesley and their great team. Thanks for your absolute dedication and hard work.

Also, much appreciation to Warren Farms and David Sanderson for their keen interest in the research and letting me use their production fields and equipment. Also, thanks to Hilltop Farms, the late George R. Massengill and son George Massengill, Jr., for providing the fertilizer, truck to deliver sweetpotatoes and warehouse, and a field to conduct one of the studies. Thanks to David Godwin in supplying for the commercial sweetpotatoes study.

Special thanks to the NC Cooperative Extension agents, Allan Thornton and Brandon Parker for their help in coordination and communications with growers. Both truly helped me in some critical points of both of my studies and gave me great advise. Thanks to the North Carolina Sweetpotato Commission for their assistance in funding some of my research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I. EFFECTS OF PREHARVEST AND POSTHARVEST TREATMENTS ON INCIDENCE AND SEVERITY OF INTERNAL NECROSIS ON ‘COVINGTON’

Fernando Montero de Espinosa Baselga, Jonathan R. Schultheis and Michael D. Boyette.

Three replicated field studies in 2016 and two in 2017 were conducted to evaluate several preharvest and postharvest treatments and how those affected occurrence of Internal Necrosis (IN) of the sweetpotato cultivar ‘Covington’. Four preharvest treatment combinations were evaluated with the application of a high chlorine versus minimal chlorine fertilizers and mowing versus not mowing prior to harvest. For the postharvest treatments, 30 roots were obtained from each preharvest plot and placed in 75ºF and 85ºF rooms in 2016 and 2017, with the addition of a 95ºF room in 2017. Roots were immediately stored in these rooms for duration after harvest of ½, 1, 2, 3 & 5 weeks in 2016, and ½ ,1 & 2 weeks in 2017, Shorter durations (1/2- and 1-week) coincided with industry recommendations while longer durations mimicked the challenges that some commercial facilities have to cool down the temperatures of rooms after curing. Once temperature and duration treatments were completed, roots were placed in a 58ºF storage room until cut. A control treatment was included where roots were not cured and placed immediately after harvest in a 58ºF storage room. Samples were cut 49 to 80 days after harvest and incidence and severity of IN were recorded. Preharvest fertilizer treatments had minimal effect on the occurrence of IN while mowing prior to harvest in most studies reduced IN incidence when roots were placed in storage for more than ½ week and exposed to temperatures of at least 75ºF. Postharvest treatments significantly impacted IN occurrence and severity, with lower

temperatures (75ºF vs 85ºF) and shorter durations (½ versus 1, 2, 3 or 5 weeks) significantly reduced IN occurrence in ‘Covington’ sweetpotato.

INTRODUCTION

North Carolina (NC) produces over 50% of the sweetpotato acreage in the U.S. with 98,000 and 90,000 acres planted in 2016 and 2017, respectively (USDA-NASS, 2018). Covington cultivar, released by the NC State University Sweetpotato Genetics and Breeding program in 2005, is a high yielder, packs out relatively high percentages of number 1 grades, and has excellent long-term storage (Yencho et al., 2008). Due to this cultivar's excellent characteristics, Covington is the most commonly grown cultivar in NC and accounts for approximately 90% (~70,000 acres) of the commercial acreage across the state (K. McIver, NC Sweetpotato Commission, personal communication). Approximately one year after 'Covington' was available commercially, a grower reported that 1600 tons of sweetpotato roots in storage had a disorder characterized by small brown to black necrotic areas in the flesh near where storage roots were removed from the stem (Jiang et al., 2015; Schultheis et al., 2009.) This disorder has been named Internal Necrosis (IN) (Clark et al., 2013b).

In general, many sweetpotato storage roots with IN are marketable due to IN symptoms being minimal. However, since initial reports of IN in 2006, IN continues to be a concern across the sweetpotato industry in NC, especially since Covington is the primary cultivar grown and it is prone to this seemingly unpredictable problem. Although the majority of IN occurrence is minimal in NC, cases exist in which severe IN is present as black or brown areas across most of the storage root's cross section, resulting in unmarketable roots (Jiang et al., 2015) (Figure 1). Even when this problem is severe it is present only in the first third to half of the length of the root from the proximal end. Thus, if the root is cut from the distal end of the root, IN may go undetected. This disorder is very problematic as no symptoms are visible externally on the root and cannot be detected unless individual roots are cut to inspect the internal flesh of the root. Internal Necrosis has resulted in lost sales of sweetpotatoes across the industry nationally and also rejected loads internationally.

Research has been ongoing since 2006 to better understand IN. Based on multi-disciplinary research at NC State University, the following has been reported regarding IN. Clones differed in degree and severity of IN susceptibility with Covington and Hatteras being the most susceptible of the clones (Clark et al., 2013a; Dittmar et al., 2010). Field studies and growers have determined that IN is not transmitted from seed roots to transplants (Schultheis and Thornton, 2007). In later studies, the use of serological, molecular and grafting methods determined that viruses did not cause IN symptoms (Golden Leaf Foundation, 2016). Experiments also found that IN is not caused by a virus or a specific combination of viruses, or associated with other pathogens (Golden Leaf Foundation, 2016; Lina Quesada, personal communication). Additional field studies determined that IN was not associated with insecticides (Jiang et al., 2015) or herbicides (Beam et al., 2017).

The results of these studies suggest that the cause of IN was not pesticide related and was not biological. Rather, it appears to be a physiological disorder that occurs in certain clones.

PREPTM, (EPA Reg. No. 264-418, Bayer Crop Science, Research Triangle, NC) an ethephon compound product composed of 55.4% ethephon and 44.6% inert ingredients is a commonly used defoliator by cotton and tobacco growers prior to harvest (Jiang et al., 2015; Beam et al., 2017). Ethephon, has been evaluated as a defoliator at harvest and as a solution to reduce the skinning of roots by tightening the skin of storage roots (Main et al., 2009; Wang et al., 2012). Some of the initial studies with ethephon were conducted on ‘Beauregard’ to evaluate the effect on skinning resistance; however, no evaluations of IN occurred because IN was unknown at the time (Schultheis et al., 2000). After IN was reported in ‘Covington’, experiments were conducted to determine the effect of ethephon applied to sweetpotato (‘Beauregard’ and ‘Covington’) foliage near harvest on IN (Dittmar et al., 2018). More occurrence and more severe incidence of IN symptoms were found in ‘Covington’ while much less incidence occurred in ‘Beauregard’ roots in ethephon treatments. Furthermore, studies in 2010, 2012 and 2015 found that ethephon application to sweetpotato was associated with more development of IN than when not applied in certain sweetpotato cultivars (Dittmar et al., 2010; Arancibia et al., 2013; Beam et al., 2017; Clark et al., 2013a; Jiang et al., 2015). However, IN symptoms were not solely associated with ethephon, as low incidence and less severe IN symptoms were also present when ethephon was not applied in ‘Covington’ (Dittmar et al., 2018). The use of foliar application of ethephon before harvest was reported to be an excellent screening mechanism in determining which clones were susceptible to IN and which were not (Clark et al., 2013a).

Since ethylene is an important hormone that affects the physiology in all plants and since its role in postharvest handling is critical, a number of sweetpotato studies have focused on postharvest where ethylene is produced by the roots (Buescher et al., 1975; Kitinoja, 1987). Besides ethylene production by sweetpotato roots, inefficient burners inside the curing rooms during storage could result in excessive levels of ethylene. Sweetpotato is very sensitive to ethylene in storage. In sweetpotato, ethylene damage is difficult to diagnose but can cause internal darkening and pithy areas (Edmunds et al., 2008). Sweetpotato is a low (~0.1 μL/kg·hr) emitter of ethylene when stored and handled properly (Cantwell and Suslow., 2001), but may produce higher levels of ethylene when wounded, infected, or subjected to chilling injury. Studies have shown that exposure to 10 ppm ethylene during or after curing enhanced levels of respiration and Polyphenol Oxidase (PPO) enzymes as well as decreased attributes of color and flavor (Buescher et al., 1975). Another study showed that sweetpotato roots exposure to ethylene, even as small as 2 ppm while curing and 1 ppm while stored, increased the respiration rates compared to the roots cured and stored with no ethylene (Kitinoja, 1987). Even though sweetpotato is sensitive to ethylene exposure, any of the symptoms caused by the increase of respiration and PPO enzymatic activities were not similar to those seen with IN damage (Buescher et al., 1975). A sweetpotato disorder "hardcore" has some similarities with IN. However, this disorder is chill-induced with more incidence and severity in 92 to 100 ppm ethylene than in ambient air (Timbie and Haard, 1977).

More recent studies were conducted to evaluate the effect of high concentrations of ethylene gas during curing and storage on IN incidence in 'Covington' sweetpotato (Jiang et al., 2015). Results from these studies revealed IN incidence was not affected by sampling date, year, or treatment with a high concentration of ethylene gas during sweetpotato storage. Only 4% of the roots from the studies had IN symptoms at the lowest level of severity.

The use of different de-vining systems like rotary or flail mowers before harvesting has been used for many years in the sweetpotato industry to halt storage root growth, aid in harvest and to reduce skinning from cuts or abrasion forces (Hayes et al., 2014; LaBonte and Wright, 1993). Skinning can result in postharvest losses due to root shrinkage (water loss), and bacterial and fungal rots (Edmunds et al., 2008). Research has found that skin adhesion is highly variable and is affected by cultivar, temperature, humidity, field of origin, physiological age of the root, and storage conditions (Villavicencio, 2002). During harvest and postharvest handling, the cuticle, epidermis, and some outer layers of the periderm separate from the underlying tissue of the storage root which may aid the process in toughening the skin.

A preliminary study suggested that mowing foliage prior to harvest in combination with the application of potash fertilizer high in chloride content (K_2O) resulted in increased IN incidence (Golden Leaf Foundation, 2016). Another preliminary study evaluated the effects of storage temperatures and its duration immediately after harvest on the occurrence and severity of IN (Golden Leaf Foundation, 2016). There was evidence to suggest that IN incidence increased when roots were exposed to 75^{o}F or 85^{o}F for one to three weeks immediately after harvest.

As discussed earlier, many factors have been investigated and systematically eliminated or need further investigation as the cause of IN in sweetpotato. Thus, the objective of these studies was to evaluate the effects of preharvest and postharvest treatments on the incidence and severity of IN affecting ‘Covington’ sweetpotato grown in NC.

METHODS

A study was conducted at Hilltop Farms (HF) (*35°36'09.6" N 78°43'20.5" W, Middle Creek, NC 27593*), Warren Farms (WF) (*35°13'31.9" N 78°06'24.8" W, Mt Olive, NC 28365)* and Cunningham Research Station in Kinston (KI) (35°18'17.7" N 77°34'52.5" W, Kinston, NC 28501) in 2016, and at WF *(35°14'18.3" N 78°20'08.9" W, Newton Grove, NC 28366)* and KI (*35°17'58.5" N 77°34'25.3" W Newton Grove, NC 28366)* in 2017. Studies at KI were established with a two-row transplanter using transplants from seed increase beds at the Horticultural Crops Research Station, Clinton NC. Studies at HF and WF were established by transplants and planting equipment from those farms. Transplant dates for the 2016 and 2017 studies were between late May and late June (Table 1) which is within the recommended sweetpotato transplant date for North Carolina (Kemble et al., 2012). The study sites were bedded rows 107 to 112 cm (42 to 44 in.) wide. The in-row crop spacing at all locations was 30.5 cm (12 in.). Each plot consisted of 8 rows 15 m (50 ft.) long and 3 m (10 ft.) alleys between the end and beginning of plots to avoid mixing of treatments and to easily distinguish plots.

Treatments

The studies were a split plot design with treatments arranged in a 2 X 2 factorial arrangement with main plots being post plant fertilizer (fert) x preharvest mowing (mow), and split-plot factors being storage temperature (temp) and storage duration (weeks).

Fertilizer treatments consisted of potassium [Muriate of potash (MP) (K_2O) or potassium sulfate (PS)(K_2O_4)] at 135 pounds applied at 7 to 14 and retreated at 21 to 41 DAP (Table 1). Muriate of potash (0-0-60) contained high chlorine, whereas, PS (0-

0-50) contained low chlorine. Elemental sulfur was applied to all MP plots at a rate of 46 pounds per acre so that those plots had the same rate of sulfate as PS plots received from PS fertilizer. Complimentary fertilizers of basic macronutrients were applied to all plots and followed the common agricultural practices for ‘Covington’ sweetpotato (Yencho et al., 2008). Calcium nitrate (15.5-0-0) was applied twice to all plots at 30 pounds N per acre per application at the same time as potassium fertilizer treatments were applied. All plots received phosphorous (0-46-0) at 30 pounds per acre at the first potassium fertilizer treatment timing.

Mowing treatments consisted of mowing the foliage approximately 2 weeks before harvest or not mowing (Table 1). The mowing equipment used at each location was a Loftness shredder (650 South Main Street. Hector MN, 55342 USA) at WF, a Bush Hog Shredder (2501 Griffin Ave. Selma, Alabama 36701) at HF and Ma PF Oelwein shredder (801 2nd Ave SE, Oelwein, IA 50662) at KI.

With the two mowing (mow) and the two potash fertilizer (fert) treatments there were a total of four preharvest treatments. A randomized complete block design with four replications was used at all five field study locations in 2016 and 2017. Layout of the field plots was the same at all study locations.

Postharvest Treatments

To determine the postharvest temperature (temp) treatment and curing/storage temperature duration (weeks) effects on incidence and severity of IN in relation to the preharvest treatments (various combinations of fertilizer (fert) and mowing (mow) treatments, 4 total). The day of harvest, twelve and ten US No.1 sample bags (each sample consisted of 6 roots from distinct plants from rows 3 to 7 of each plot totaling 30 roots per sample) were collected from each plot in 2016 and 2017, respectively, and then subjected to weeks and temp treatments (Table 2). An extra sample bag was collected and roots were cut in the field the same day of harvest to determine if IN was present immediately after harvest.

Harvest for each study ranged from late September to early November; 113 to 127 DAP (Table 1). The postharvest treatments for both years were conducted in the curing facilities at the Horticultural Crops Research Station, Clinton, NC. Hobo data loggers (Hobo® ONSET® UX100 -003) recorded percentage relative humidity (RH) and temperature (ºF) and were placed in each room both years to track these measurements throughout the treatment time and validate the computer settings. Once the roots were harvested and transported to the research station in Clinton, lugs holding one individual mesh bag with the 30 roots were put into their corresponding treatment rooms. Rooms were preheated to the desired temperature (75ºF or 85ºF in 2016 and 2017 or 95ºF in 2017 only) and RH (targeted at 85%). Root storage duration treatments (weeks) were ½, 1, 2, 3 and 5 weeks in 2016 and ½, 1 and 2 weeks in 2017. The treatments labeled as “NO CURE” (0 week) were placed directly into the 58ºF storage room. Once the temp and weeks treatment was achieved (i.e. 75ºF – 2 weeks) the lugs holding the mesh bags were moved into the 58ºF room.

Although curing in commercial rooms is normally no more than one week (Edmunds et al., 2008; Walter and Schadel, 1982), temperature duration treatments (weeks) were extended to 5 weeks in 2016 and 2 weeks in 2017 to mimic conditions that can occur in commercial storage rooms due to the inability of growers to reduce curing temperature (75ºF to 85ºF) to storage temperatures (58ºF) in a timely manner.

Sampled roots from 2016 and 2017 were cut into 0.1-inch sections starting at the proximal end of the sweetpotato until about 1/3 to 1/2 of the root was cut between 49 and 80 days after harvest (Table 1) and then visually rated for severity on a scale of 1 to 5, 1= No IN and 2 to 5 with increased IN severity as the number increases (Figure 1). Incidence and severity ratings of each sample were evaluated by the same person to assure rating consistency. Incidence (%) was recorded as the number of roots per 30 sampled roots per bag that had any symptoms of IN. Internal Necrosis severity was averaged for only those roots that had IN symptoms. These data were analyzed using Proc Mixed (SAS/STAT software, Version 9.4 M3 of the SAS System for Windows). The experiment was a split plot design at three locations in 2016 and repeated in two locations in 2017. The whole plot factors, mow and fertilizer, were arranged in a 2x2 factorial. Both years had the same 4 whole plot treatments; Mow/PS, Mow/MP, NoMow/PS and NoMow/MP. The postharvest split plot factors were the curing/storage duration (weeks) and temperature (temp). In 2016 the curing times were 1/2, 1, 2, 3, 5 weeks and in 2017 the curing times were 1/2, 1, 2 weeks. In 2016 the temp were 75ºF, 85ºF in 2017 and the temp were 75ºF, 85ºF, 95ºF. Due to excessive RH in the curing units, the 95ºF data were not included in the analysis. Both years also included a control treatment at 58ºF that was not included in the analysis because these data did not have a comparable storage duration treatment (weeks) as the 75ºF and 85ºF temp treatments. Separation of significance between treatment means was conducted using the Tukey-Kramer procedure.

RESULTS & DISCUSSION

Some irregularities in the postharvest treatments occurred in the storage rooms at the Horticultural Crops Research Station in Clinton, NC during the 2016 studies. Electricity was lost due to Hurricane Mathew from October 8 to 10. During those days, temperatures in the 75ºF and 85ºF chambers where the roots were being held had temperatures below 70ºF, which disrupted the temperature duration treatments (1, 2, 3 and 5 weeks after harvest) for the WF study since those roots were harvested October 3. (Appendix, Table 1). The 75ºF temp treatment remained relatively consistent after October 10, fluctuating no more that 1 to 2ºF through the rest of the treatment durations (weeks) for the HF, WF, and KI studies. The other temp treatment (85ºF) generally ranged between 81ºF to 82ºF from October 10 until the end of the study and was three to four degrees lower than the targeted temperature. Thus, we will reference the 85ºF treatment in the remainder of this section for 2016 as 82ºF.

In 2017 the postharvest treatments were modified as described in the methods section. Average temperatures in the 75ºF treatment room ranged between 75ºF and 77ºF with relative humidity (RH) that ranged between 81% and 87% (Appendix, Table 2). The 85ºF treatment room ranged between 83ºF and 84ºF and RH between 87% and 92%, while the 95ºF treatment room had very stable temperatures, ranging between 93ºF to 95ºF; however, the RH remained high between 97% and 98% and roots were covered with water from condensation, not typically encountered in commercial facilities. The 58ºF treatment room ranged in temperatures between 60ºF and 63ºF and RH between 78% and 82% for the entire duration (weeks) of the study, until roots were cut.

The results are presented separately for 2016 and 2017 because the postharvest treatments differed between years. In addition, studies are presented separately for each year because some interactions between mowing and postharvest treatments were significant for some studies but not others (Tables 3, 4 & 5). A likely reason for treatment differences between study locations is due to environmental variations between years that occurred (Appendix, Tables 3, 4 & 5).

There were no four-way interactions observed for mow x fert x weeks x temp for incidence or severity of IN (Tables 3, 4, & 5). Only in the KI studies, was one three-way interaction observed in 2016 and 2017 at the $P > 0.05$ (Table 5). A two-way interaction was observed in each of the WF studies in 2016 and 2017 (Table 4), while two main effects were significant in the HF study in 2016 (Table 3). As appropriate, these significant interactions and main effects will be presented and discussed to explain the results.

Results on IN severity were analyzed both years but few differences among preharvest and postharvest treatments were observed. An interaction between mow x temp was observed in 2016 with KI where the No Mow treatment roots in the 85ºF and 75ºF treatments had 2.7 IN severity and 2.6, respectively. In 2017 at WF the main effect temp was significant ($P<0.0002$) with high (3.0) IN severity in the 85ºF and less than 2.1 at 75ºF. The interaction between mow x weeks, and the main effect temp were also significant in KI in 2017. For example, higher severity resulted when roots were exposed to 85ºF (2.9) compared to 75ºF (2.6). Although few differences were detected between certain treatments with respect to IN severity, these differences seemed to have little practical effect on the marketability of roots. Furthermore, the increase of IN incidence increased in a similar manner as IN symptoms; the more roots with IN incidence, the greater the IN severity (Figure 2). Since IN incidence and severity responses were similar, we will present results for IN incidence only.

2016. In the HF study, the only treatments affecting the incidence of IN were the main effects of postharvest treatments for weeks and temp (Table 3). Preharvest treatments were not significant in the HF study. Roots exposed to 82ºF treatment had 12% IN incidence versus 9% IN at 75ºF at P=0.0060. It should be noted that when roots were placed directly into a 58ºF temperature chamber immediately after harvest and not exposed to curing or warmer temperature treatments a 5% IN incidence was recorded. Although IN incidence was detected, severity was minimal with ratings of 2 and 3 (Figure 1). These roots would likely be marketable. Roots with very minimal severity like those observed in the no cure (58ºF) treatment were scored as IN; however, these pencil dot symptoms could be due to other factors besides IN and could be confused with chilling injuries (Cantwell and Suslow, 2001) or a virus (Golden Leaf Foundation, 2016) that may exhibit similar symptoms. Because IN symptoms have not been associated with biotic factors such as disease, isolation of a microorganism from a symptomatic root was not possible (Golden Leaf Foundation, 2016). Internal necrosis incidence increased when roots were exposed to either 75ºF or 82ºF for up to two weeks (Table 6) with 2%, 6% and 10% IN incidence observed at ½, 1, and 2 weeks, respectively after temp treatment. After 2 weeks IN incidence leveled off to 12% and 10% at 3 and 5 weeks, respectively. The increase of IN incidence in ‘Covington’ roots over time when exposed to temp treatments (75ºF or 82ºF) for longer periods of time agrees with some preliminary work conducted in 2015 (Golden Leaf Foundation, 2016).

As in the HF study, both the main effects of temp and weeks were significant for the WF study (Table 4). In addition, for the WF study, there was a significant interaction between temp and weeks at the P=0.0062 level. Internal necrosis incidence was higher at 2 and 5 weeks when roots were exposed to the 82ºF treatment versus the 75ºF treatment (14% versus 6%, respectively) (Table 7). As in the HF study, no significant increase in IN incidence was observed after 2 weeks, regardless of temp treatment. Results in the WF study, with respect to weeks, were similar to those in the HF study. For these two locations the ambient conditions at harvest were similar (temperatures 71ºF WF and 64ºF HF) and mowing was 17 and 12 days before harvest, respectively.

Response to treatments in the KI study differed from the HF and the WF studies. With respect to IN occurrence, both the postharvest treatments, weeks and temp, were very significant (P > 0.01) (Table 5); however, each of these treatments interacted with various preharvest treatments. A two-way interaction between mow x weeks (Table 8) was observed. When foliage was mowed, IN incidence remained stable ranging from 2 to 5% when exposed to temp treatments from ½ to 5 weeks. When foliage was not mowed, IN incidence was increased at 2 and 5 weeks (8 and 12%, respectively) compared to when foliage was not mowed. This observation is contrary to what was reported in a preliminary study when the practice of mowing resulted in more IN than when not mowed (Golden Leaf Foundation, 2016). No difference in IN occurrence was detected due to mowing in the HF and WF studies. The reason why a response for HF and WF was not obtained but a response for KI was obtained remains uncertain. Rainfall impacted when mowing treatment occurred (Table 1). Days from mowing to harvest differed between KI (22 days), WF (17 days) and HF (11 days). The difference of 5 days between KI and WF and the 11 days between HF and KI from mowing to harvest may be an important consideration and possible reason for the varying response to mowing in 2016 studies. Although mowing seemed to have a positive effect on IN incidence, it remains unknown as to how many days prior to harvest and what environmental conditions facilitate or would mitigate against IN occurrence. Mowing reduced the occurrence of IN in the KI location and followed the same trend in the WF study but was not significant (5% when mowed and 9% when not mowed). Temperatures at harvest for each study location and year also varied (Appendix, Tables 3, 4, & 5) being as high as 76ºF in the KI study location and as low as 64ºF in HF for 2016. The difference of the pulp temperature inside the roots from each study when postharvest treatments started could also contribute to these different mow treatment responses between study locations. Future research should consider pulp temperature measures at harvest to determine the potential preharvest effect on IN incidence.

Fertilizer treatment was a contributing factor in IN incidence as a significant mow x fert x temp interaction was observed (Table 5). Mowed or not mowed treatments using PS fertilizer were not significant whether temp was 75ºF or 82ºF. With MP (high chlorine fertilizer) x vines mowed x 82ºF treatments, 11% IN incidence resulted compared to 5% or less for all other treatment combinations. The higher incidence of IN in the MP versus PS treatments were first reported in a preliminary study (Golden Leaf Foundation, 2016). It has been reported that there are detrimental effects on cured leaf yield, quality, chemistry and nutrient assimilation of tobacco when high levels of chlorides (> 44 Kg per hectare) are supplied through MP during the growing season (Garner et al., 1930; Skogley, 1962; McCants et al., 1967). Because tobacco growers commonly grow sweetpotatoes and use MP, the high levels of chlorine may be a possible factor in the IN occurrence in sweetpotato when vines are not mowed and roots are exposed to relatively warm storage conditions.

2017. In WF and KI studies, the 95ºF temp treatment was not included in the statistical analysis. Temperature was well maintained in the treatment room; however, RH was near 100%. Roots in this room were covered with water from condensation resulting in several roots rotting. Roots sampled did not exhibit any IN. In a concurrent related study conducted at a commercial sweetpotato storage facility, roots exposed for a week to temperatures above 85ºF (95ºF for five days) had a high occurrence of IN (average 70%). However, relative humidity recorded in this room was low (average 77% RH) compared to RH conditions that occurred in the storage rooms at the research station, and roots were not covered with water from condensation. The high RH may have inhibited IN development as the physiology of storage roots changes with humidity. The humidity factor in sweetpotato storage has not received the attention deserved (Jones and Rosa, 1928). Humidity recommendations for sweetpotato storage have not changed for many years (Boyce et al., 1956). Few studies have looked at physiological changes other than suberization and formation of wound periderm to prevent postharvest diseases. Some studies evaluated the biochemical effects in sweetpotatoes due to storage humidity (Boyce et al., 1956; Jones and Rosa, 1928; Nabubuya et al., 2017) where changes in carotene or ascorbic acid during storage were not significantly affected by RH. The amount of existing sugars could be modified after storage. Sweetpotatoes stored at 15°C had less weight loss than those stored under ambient conditions (23.8 ~ 28.4°C and 77.1 ~ 81.0% relative humidity) (Huang et al., 2014). Also, low humidity (70–75%) was reported to hasten internal breakdown and shorten storage shelf life. Future studies should also evaluate the effects of high temperatures at varying RH on IN occurrence.

As in the WF study in 2016 and in the 2017, no significant differences between fert treatments were observed (Table 4). The preharvest mow treatment was significant at the P= 0.0035 level and so was the interaction between the mow x weeks interaction at WF in 2017. Similar to the KI study in 2016 (Table 8), treatment response was similar in 2017 at the WF location (Table 4) with the magnitude of IN occurrence appearing to be greater in the 2017 study than in the 2016 study. In 2017, for the no mow treatment, IN incidence increased from ½ to 1 to 2 weeks, (3%, 20% and 32%, respectively) (Table 10). The IN incidence for the mowed treatments were also greater as weeks increased (3%, 10% and 14%, respectively) but were lower than the no mow treatment after 1 and 2 weeks. When storage roots were stored for as little as 1-week compared to 1/2-week, the incidence of IN increased. The main effect of temp also had a significant impact on IN incidence as incidence was greater (16%) at 85ºF compared to 11% at 75ºF. The importance of using an abbreviated, cooler than recommended treatment in commercial facilities appears crucial to minimize IN occurrence in 'Covington'.

In the 2017 KI study, a mow x temp interaction was observed that affected incidence of IN (Table 5). Incidence was highest (21%) when the vines were not mowed and roots stored at 85ºF compared to not mowed and roots stored at 75ºF (7%) (Table 11). In the 2017 KI study, a three-way interaction between mow, fert and weeks was observed with respect to IN incidence as both preharvest treatments affected IN incidence (Table 12) (Figure 3). The postharvest factor weeks generally increased the incidence of IN as weeks increased from ½ to 2 weeks for most of the preharvest combinations. When plots were mowed and PS fertilizer was applied, IN was less than 10% for ½, 1 and 2 weeks, while 14% IN incidence occurred at 2 weeks when MP fertilizer was applied. Increased IN incidence occurred earlier in the not mowed treatment with the MP treatment versus the PS treatment (1/2 to 2 weeks). These results provide support to the hypothesis that occurrence of IN is due to a combination of both preharvest and postharvest factors.

A preharvest mowing treatment consistently had the least IN incidence in 3 of the 5 studies. Mowing has the added benefit of reducing skinning of sweetpotatoes (Edmunds et al., 2008; LaBonte and Wright, 1993). Future research should evaluate specifically when mowing should be done prior to harvest under a range of environments to reduce IN incidence, and provide the sweetpotato industry with a way to potentially provide a consistent way to reduce IN. The 58ºF treatment resulted in very minimal incidence and severity of IN both years (3-5% in 2016 and 0% in 2017). By avoiding the standard recommended practices of curing at 85ºF and 85 to 90% RH (Thompson et al., 2002; Edmunds et al., 2008), IN incidence and severity did not occur or was minimal. Beyond minimizing or avoiding IN in ‘Covington’ sweetpotato, curing is recommended to heal the wounds caused at harvest and helps to reduce disease incidence improving quality of the roots and enhancing flavor and appearance. (Boyette et al., 1994; Edmunds et al., 2008; Picha et al., 1986; Villavicencio et al., 2002). The higher temperatures (85ºF or 82ºF) consistently result in an increase of IN incidence in ‘Covington’ when compared to lower temperatures (75ºF). These studies demonstrated that exposure to 75ºF or 85ºF for one to two weeks increased IN incidence. The effects of lowering temperatures during curing of ‘Covington’ appears to be critical in minimizing IN occurrence. However, minimal or no curing may negatively impact the storability and other quality aspects of sweetpotatoes long term. Future research needs to evaluate this so that a balance between sweetpotato shelf life, quality and minimizing IN is maintained.

REFERENCES

Arancibia, R.A., J.L. Main, and C.A. Clark. 2013. Sweetpotato tip rot incidence is increased by preharvest applications of ethephon and reduced by curing. HortTechnology 23:288–293.

Beam, S.C., K.M. Jennings, D.W. Monks, J.R. Schultheis, and S. Chaudhari. 2017. Influence of herbicides on the development of internal necrosis of sweetpotato ((*Ipomoea batatas* (L.)(Lam). Weed Technol. 31:863–869.

Boyce D.E., S.W. Marguerite and D.D. Kenneth. 1956. Biological and biochemical effects of storage humidity on sweet potatoes. Biological Bioscience Branch, Agricultural Marketing Service, USDA, Beltsville, Md.

Boyette, M. D., and H. E. Stewart. 1994. Horizontal ventilation for long-term storage of sweetpotatoes. ASAE Paper No. 946583. St. Joseph, Mich.: ASAE.

Buescher, R.W., W.A. Sistrunk, and P.L. Brady. 1975. Effects of ethylene on metabolic and quality attributes in sweetpotato roots. J. Food. Sci. 40(5):1018-1020.

Cantwell, M. and T. Suslow. 2001. Sweet potato: recommendations for maintaining postharvest quality. Dept. Plant Sci., UC-Davis, Davis, CA. http://postharvest.ucdavis.edu/pfvegetable/SweetPotato/

Clark, C.A.,W.L. Da Silva, R.A. Arancibia, J.L. Main, J.R. Schultheis, Z. Pesic van-Esbroeck, C. Jiang, and J. Smith. 2013a. Incidence of end rots and internal necrosis in sweetpotato is affected by cultivar, curing, and ethephon defoliation. HortTechnology 23:886–897.

Clark, C.A., D. Ferrin, T. Smith and G. Holmes., 2013b. Compendium of sweetpotato diseases, pests, and disorders. Phytopathology. 2nd ed. p.144.

Dittmar, P.J., K.M. Jennings, D.W. Monks, and J.R. Schultheis. 2010. Determining the effect of ethylene on internal black marbling expression in sweetpotato. HortScience 45:488–489 (Abstr.).

Dittmar, PJ., J.R. Schultheis, K.M. Jennings, D.W. Monks, S. Chaudhari, S. Meyers, and C. Jiang. 2018. Effect of cultivar, ethephon, flooding and storage duration on sweetpotato internal necrosis. HortTechnology 28(3):246-250.

Edmunds, B.A, M. Boyette, C.A. Clark, D. Ferrin, T. Smith, and G. Holmes. 2008. Postharvest handling of sweetpotatoes. N.C. Cooperative Extension Service. p.12. Raleigh, NC.

Garner, W.W, J. E. McMurtrey, J. D. Bowling, and E. G. Moss, 1930. Role of chlorine in nutrition and growth of the tobacco plant and its effect on the quality of the cured leaf. J. Agr. Res., 40, 627- 648.

Golden Leaf Foundation, 2016. Determining the cause and control of internal necrosis in sweetpotatoes. Project number 14-147 final project, 301 North Winstead Avenue. Rocky Mount, NC 27804.

Hayes B.H., J.K. Ward, B. Hayes, J.W. Lowe, J. Davis, M. Shankle, and R.A. Arancibia, 2014. Development of mechanical undercutting system to minimize sweetpotato skinning during harvest. ASAE. Vol. 30(3): 355-360.

Huang, C. L., W. C. Liao, C. F. Chan, Y. C. Lai, 2014. Storage performance of Taiwanese sweetpotato cultivars. J. Food Sci. 51(12), 4019–4025.

Jiang, C., P. Perkins-Veazie, S.M. Blankenship, M.D. Boyette, Z. Pesic-VanEsbroeck, K.M. Jennings, and J.R. Schultheis. 2015. Occurrence, severity, and initiation of internal necrosis in ‘Covington’ sweetpotato. HortTechnology 25:340–348.

Jones, H.A., and J.T. Rosa.1928. Truck Crop Plants. McGraw-Hill, New York.

Kemble, J.M., K. Ivors, F.J. Louws, K.M. Jennings, and J.F. Walgenbach (eds.). 2012. Southeastern U.S. 2012 vegetable crop handbook. p. 96-97. Du Pont.

Kitinoja, L.A. 1987. Effects of low concentrations of ethylene on sweetpotatoes (Ipomoea batatas (L.) (Lam) during curing and storage. Acta Hort. 201:37-42.

LaBonte, D.R. and M.E. Wright. 1993. Image analysis quantifies reduction in sweetpotato skinning injury by preharvest canopy removal. HortScience. 28(12):1201.

Main, J.L., M.W. Shankle, and T.F. Garrett. 2009. A comparison of ethephon and conventional vine removal systems for Mississippi sweetpotato. HortScience. 44(3):574-574 (Abstr.).

McCants, C.B. and W.G. Woltz. 1967. Growth and mineral nutrition of tobacco. Advances in Agronomy 19:211-265.

Nabubuya A, A. Namutebi, Y. Byaruhanga, J. Narvhus, and T. Wicklund. 2017. Influence of development, postharvest handling, and storage conditions on the carbohydrate components of sweetpotato (*Ipomoea batatas* (L.) (Lam.) roots. Food Sci. Nutr. 5:1088–1097.

Picha, D. H. 1986. Weight loss in sweetpotatoes during curing and storage: Contribution of transpiration and respiration. J. American Soc. of Hort. Sci. 111: 889-892.

Schultheis, J.R, Blankenship, S., Monks, D., & Boyette, M. 2000. Preharvest methods to reduce skinning in ‘Beauregard’ sweetpotato. HortScience. 35(3):444 (Abstr.).

Schultheis, J.R., Z. Pesic-VanEsbroeck, K.M. Jennings, P.J. Dittmar, and A.C. Thornton. 2009. Effects of environmental stress and pathogens on the internal mottling and end rots of sweetpotato in new commercial varieties (‘Hatteras’ and ‘Covington’) and established commercial varieties (‘Beauregard’ and ‘Carolina Rudy’). North Carolina sweetpotato research and extension reports 2009. NC State Univ., Raleigh, NC.

Schultheis, J.R. and A.C. Thornton. 2007. Determining the expression or lack of expression of internal marbling in Covington roots via vegetative propagation during the growing season and in storage; refinement of nitrogen application rate and timing to optimize yields and root sizing of Covington sweetpotato. North Carolina sweetpotato research and extension reports 2007. NC State Univ., Raleigh, NC.

Skogley, FA. 1962. Nature and mechanisms of ammonium and chloride influences on growth and properties of tobacco. MS Thesis, North Carolina State Univ. Raleigh, NC.

Thompson, P., M. Williams, J. Byrd, J. Thomas, D. Parvin, and F. Killerbrew. 2002. Commercial Sweetpotato Production in Mississippi. Mississippi State Univ. Extension Service. MSU-CARES, Publication 1678. http://msucares.com/pubs/publications/p1678.html

Timbie, M. and N.F. Haard. 1977. Involvement of ethylene in hardcore syndrome of sweet-potato roots. J. Food Sci. 42(2):491-493.

Villavicencio, L. 2002. Physiological aspects of skin adhesion in sweetpotato (Ipomoea batatas (L.) Lam.). PhD diss. North Carolina State Univ. Raleigh, N.C.

Walter, Jr., W.M., and W.E. Schadel. 1983. Structure and composition of normal skin (periderm) and wound tissue from cured sweetpotatoes. J. Amer. Soc. Hort. Sci. 108(6):909–914.

Wang, X., R.A. Arancibia, J.L. Main, and M. Shankle. 2012. Pre-harvest application of ethephon enhances skin lignification and increases the force required to peel sweetpotato storage roots. ASHS-HortTalks, Miami, FL (Abstr.).

Yencho, G.C., K.V. Pecota, J.R. Schultheis, Z. Pesic-Vanesbroeck, G.J. Holmes, B.E. Little, A.C. Thornton, and V. Truong. 2008. ‘Covington’ sweetpotato. HortScience 43(6):1911-1914.

[USDA-NASS] U.S. Dept. Agr. 2018 – National Agricultural Statistical Service. http://quickstats.nass.usda.gov/results

Table 1. Critical cultural management practices for the preharvest treatments at Warren Farms, Kinston and Hilltop Farms study locations during 2016 and 2017.

PRACTICE EMPLOYED	LOCATION 2016		
	Warren Farms	Kinston	Hilltop Farms
Transplanting	June 12	June 17	June 28
1st fertilizer application	June 24	June 27	July 12
2nd fertilizer application	July 14	July 11	August 8
Mowing Days Before Harvest (DBH)	September 16 17 DBH	September 26 22 DBH	October 21 12 DBH
Harvest Days After Planting (DAP)	October 3 113 DAP	October 19 124 DAP	November 2 127 DAP
Sample cutting Days After Harvest (DAH)	November 21 49 DAH	December 14 56 DAH	January 10 69 DAH

	2017	
	Warren Farms	Kinston
Transplanting	May 31	June 1
1st fertilizer application	June 7	June 9
2nd fertilizer application	June 27	June 28
Mowing Days Before Harvest (DBH)	September 15 14 DBH	September 8 14 DBH
Harvest Days After Planting (DAP)	September 29 121 DAP	September 22 113 DAP
Sample cutting Days After Harvest (DAH)	December 13 75 DAH	December 11 80 DAH

Table 2. Postharvest treatments for the 12 bags per plot in 2016 and 11 bags in 2017.

	2016		2017	
Sampled bags per plot	Temp ºF	Weeks	Temp ºF	Weeks
Bag 1[z]	------	0 – Cut at harvest[Y]	------	0 – Cut at harvest
Bag 2	58ºF	0 – Control Trmt.	58ºF	0 – Control Trmt.
Bag 3	75ºF	½ Weeks	75ºF	½ Weeks
Bag 4	75ºF	1 Weeks	75ºF	1 Weeks
Bag 5	75ºF	2 Weeks	75ºF	2 Weeks
Bag 6	75ºF	3 Weeks	85ºF	½ Weeks
Bag 7	75ºF	5 Weeks	85ºF	1 Weeks
Bag 8	85ºF	½ Weeks	85ºF	2 Weeks
Bag 9	85ºF	1 Weeks	95ºF	½ Weeks
Bag 10	85ºF	2 Weeks	95ºF	1 Weeks
Bag 11	85ºF	3 Weeks	95ºF	2 Weeks
Bag 12	85ºF	5 Weeks	-------	-----------

[Z] For each bag numeric designation, a 30-root sample was obtained from each plot, which totaled 16 bags for each temperature and week treatment.
[Y] Samples were cut in the field at harvest to confirm no IN coming from the field prior to postharvest treatment.

Table 3. Type 3 tests of fixed effects from HF location in 2016 with a P-value =.05.

Effect	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Mow	1	12	2.42	0.1456
Fert	1	12	0.02	0.8972
*Mow*Fert*	1	12	0.016	0.6993
Weeks	4	108	13.01	< .0001
*Mow*Weeks*	4	108	0.62	0.6505
*Fert*Weeks*	4	108	0.23	0.9200
*Mow*Fert*Weeks*	4	108	0.70	0.5969
Temp	1	108	7.85	0.0060
*Mow*Temp*	1	108	1.47	0.2279
*Fert*Temp*	1	108	1.27	0.2614
*Mow*Fert*Temp*	1	108	0.04	0.8348
*Weeks*Temp*	4	108	1.09	0.3667
*Mow*Weeks*Temp*	4	108	0.99	0.4140
*Fert*Weeks*Temp*	4	108	0.81	0.5223
*Mow*Fert*Weeks*Temp*	4	108	0.41	0.8035

Table 4. Type 3 tests of fixed effects from WF location in 2016 & 2017 with a P-value =.05.

2016

Effect	Num DF	Den DF	F Value	Pr > F
Mow	1	12	2.52	0.1378
Fert	1	12	2.52	0.1378
*Mow*Fert*	1	12	1.00	0.3376
Weeks	4	108	13.10	< .0001
*Mow*Weeks*	4	108	1.05	0.3830
*Fert*Weeks*	4	108	1.41	0.2342
*Mow*Fert*Weeks*	4	108	1.17	0.3264
Temp	1	108	15.97	0.0001
*Mow*Temp*	1	108	0.53	0.4667
*Fert*Temp*	1	108	2.01	0.1591
*Mow*Fert*Temp*	1	108	0.22	0.6374
*Weeks*Temp*	4	108	3.80	0.0062
*Mow*Weeks*Temp*	4	108	0.28	0.8935
*Fert*Weeks*Temp*	4	108	1.61	0.1761
*Mow*Fert*Weeks*Temp*	4	108	0.16	0.9586

2017

Mow	1	12	13.15	0.0035
Fert	1	12	3.53	0.0847
*Mow*Fert*	1	12	1.97	0.1861
Weeks	2	60	38.94	< .0001
*Mow*Weeks*	2	60	7.34	0.0014
*Fert*Weeks*	2	60	0.78	0.4630
*Mow*Fert*Weeks*	2	60	1.76	0.1805
Temp	1	60	5.78	0.0193
*Mow*Temp*	1	60	2.07	0.1557
*Fert*Temp*	1	60	0.00	0.9858
*Mow*Fert*Temp*	1	60	0.90	0.3470
*Weeks*Temp*	2	60	0.38	0.6884
*Mow*Weeks*Temp*	2	60	1.23	0.2982
*Fert*Weeks*Temp*	2	60	1.76	0.1808
*Mow*Fert*Weeks*Temp*	2	60	0.01	0.9912

Table 5. Type 3 tests of fixed effects from KI location in 2016 & 2017 with a P-value =.05

2016

Effect	Num DF	Den DF	F Value	Pr > F
Mow	1	12	14.28	0.0026
Fert	1	12	3.24	0.0971
*Mow*Fert*	1	12	2.92	0.1130
Weeks	4	108	11.53	< .0001
*Mow*Weeks*	4	108	6.19	0.0020
*Fert*Weeks*	4	108	1.36	0.2522
*Mow*Fert*Weeks*	4	108	1.81	0.1319
Temp	1	108	15.81	0.0001
*Mow*Temp*	1	108	8.36	0.0046
*Fert*Temp*	1	108	3.72	0.0565
*Mow*Fert*Temp*	1	108	4.20	0.0429
*Weeks*Temp*	4	108	0.73	0.5736
*Mow*Weeks*Temp*	4	108	0.76	0.5544
*Fert*Weeks*Temp*	4	108	0.70	0.5907
*Mow*Fert*Weeks*Temp*	4	108	0.49	0.7404

2017

Mow	1	12	18.93	0.0008
Fert	1	12	2.21	0.1627
*Mow*Fert*	1	12	0.07	0.8026
Weeks	2	60	22.34	< .0001
*Mow*Weeks*	2	60	3.98	0.0238
*Fert*Weeks*	2	60	0.58	0.5627
*Mow*Fert*Weeks*	2	60	4.16	0.0202
Temp	1	60	73.42	< .0001
*Mow*Temp*	1	60	7.73	0.0072
*Fert*Temp*	1	60	0.01	0.9312
*Mow*Fert*Temp*	1	60	0.46	0.4980
*Weeks*Temp*	2	60	2.51	0.0898
*Mow*Weeks*Temp*	2	60	0.60	0.5513
*Fert*Weeks*Temp*	2	60	0.00	0.9982
*Mow*Fert*Weeks*Temp*	2	60	0.63	0.5379

Table 6. Effects of storage duration (weeks) to temperature treatment on the incidence of internal necrosis. Hilltop Farms, 2016.

Weeks Exposed to 75 or 82ºF[Z]	% Internal Necrosis
0[Y]	5
½	2 c[X]
1	6 b
2	10 ab
3	12 a
5	10 b

[Z] Weeks at temperatures of 75ºF or 82ºF.

[Y] Roots not exposed to high temperature treatment (75ºF and 82ºF) but placed in 58ºF storage room immediately after harvest. Not included in the analysis.

[X] Significant at the <0.5 level when letters differed between storage duration (weeks).

Table 7. Effects of storage duration (weeks) in combination with temperature treatment on the incidence of internal necrosis. Warren Farms, 2016.

Temperature Duration (weeks)[Z]	Temperature	
	75ºF	82ºF
½	1 d[Y]	1 d
1	2 bc	6 bc
2	6 bc	14 a
3	9 ab	8 ab
5	6 bc	14 a

[Z] Roots not exposed to high temperature treatment (75ºF and 82ºF) but placed in 58ºF storage room immediately after harvest. Not included in the analysis.
[Y] Significant at the <0.5 level when letters differed between temperature x duration (weeks) treatment across rows and columns.

Table 8. Effects of mow treatment in combination with storage duration on the incidence of internal necrosis. Kinston, 2016 & 2017.

	Weeks Exposed to 75 or 82/85ºF[Z]									
	2016						2017			
Mowing Trmt	0[Y]	½	1	2	3	5	0[Y]	½	1	2
Mowed	0	0 c[X]	2 c	5 bc	2 c	2 c	0	3 d	7 cd	11 bc
Not Mowed	0	1 c	3 c	8 ab	4 bc	12 a	0	6 cd	18 ab	18 a

[Z] Temperature treatments for 2016 were 75ºF and 82ºF. Temperature treatments for 2017 were 75ºF and 85ºF.

[Y] Roots not exposed to high temperature treatment (75ºF and 82ºF) but placed in 58ºF storage room immediately after harvest. Not included in the analysis.

[X] Significant at the <0.5 level when letters differed between mowing treatment x curing duration.

Table 9. Effects of mow treatment in combination with fertilizer and temperature on the incidence of internal necrosis. Kinston, 2016.

	Mowing Treatments				
	Mow			Not Mowed	
Temperature	PS	MP	Fertilizer Trmt.	PS	MP
75ºF	2 b[Z]	2 b		3 b	4 b
82ºF	3 b	3 b		5 b	11 a

[Z] Significant at the <0.5 level when letters differed between temperature x mowing x fertilizer treatment.

Table 10. Effects of mow treatment in combination with storage duration (weeks) on the incidence of internal necrosis. Warren Farms, 2017.

	Weeks Exposed to 75ºF or 85ºF			
Mowing Trmt	0[Z]	½	1	2
Mowed	0	3 c[Y]	10 bc	14 b
Not Mowed	0	3 c	20 b	32 a

[Z] Roots not exposed to high temperature treatment (75ºF and 82ºF) but placed in 58ºF storage room immediately after harvest. Not included in the analysis.
[Y] Significant at the <0.5 level when letters differed between storage duration x mowing treatment.

Table 11. Effects of mow treatment in combination with temperature treatment on the incidence of internal necrosis. Kinston, 2016 & 2017.

	Temperature			
	2016		2017	
Mowing Trmt	75ºF	82ºF	75ºF	85ºF
Mowed	2 b[z]	3 b	3 c	11 b
Not Mowed	3 b	8 a	7 bc	21 a

[Z] Significant at the <0.5 level when letters differed between mowing x temperature treatment.

Table 12. Effects of mow treatment in combination with storage duration (weeks) and fertilizer on the incidence of internal necrosis. Kinston, 2017

	Weeks Exposed to 75 or 85ºF							
	MP				PS			
Mowing Trmt.	0[Z]	½	1	2	0[Z]	½	1	2
Mowed	0	5 cd[Y]	5 cd	14 abc	0	2 d	8 bcd	8 bcd
Not Mowed	0	5 cd	22 a	19 ab	0	7 cd	13 abcd	18 ab

[Z] Roots not exposed to high temperature treatment (75ºF and 82ºF) but placed in 58ºF storage room immediately after harvest. Not included in the analysis.
[Y] Significant at the <0.5 level when letters differed between mowing treatment x weeks duration x fertilizer.

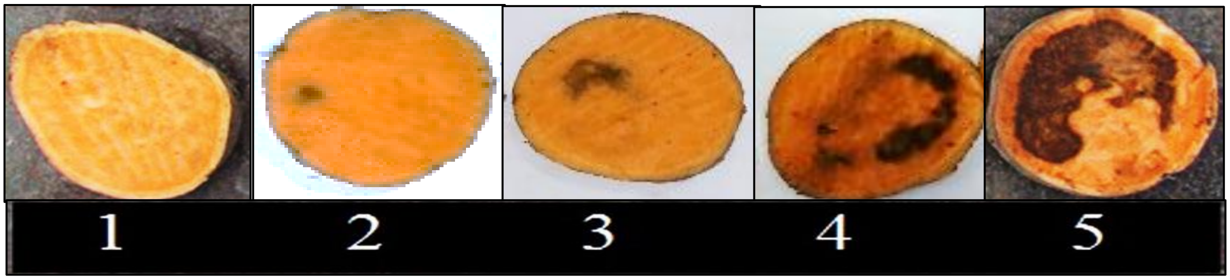

Figure 1. Grading cards used for rating Internal Necrosis severity. 1 = no internal necrosis incidence, 2 = least severe and still marketable root, < 5% necrotic, 3 = darker necrotic tissue with limited necrotic area still marketable, 5 to 20% necrotic, 4 = Necrotic tissue covers 21-60% of the sampled root, darker color, not marketable, 5 = Necrotic tissue covers > 60% of the sample, dark and not marketable.

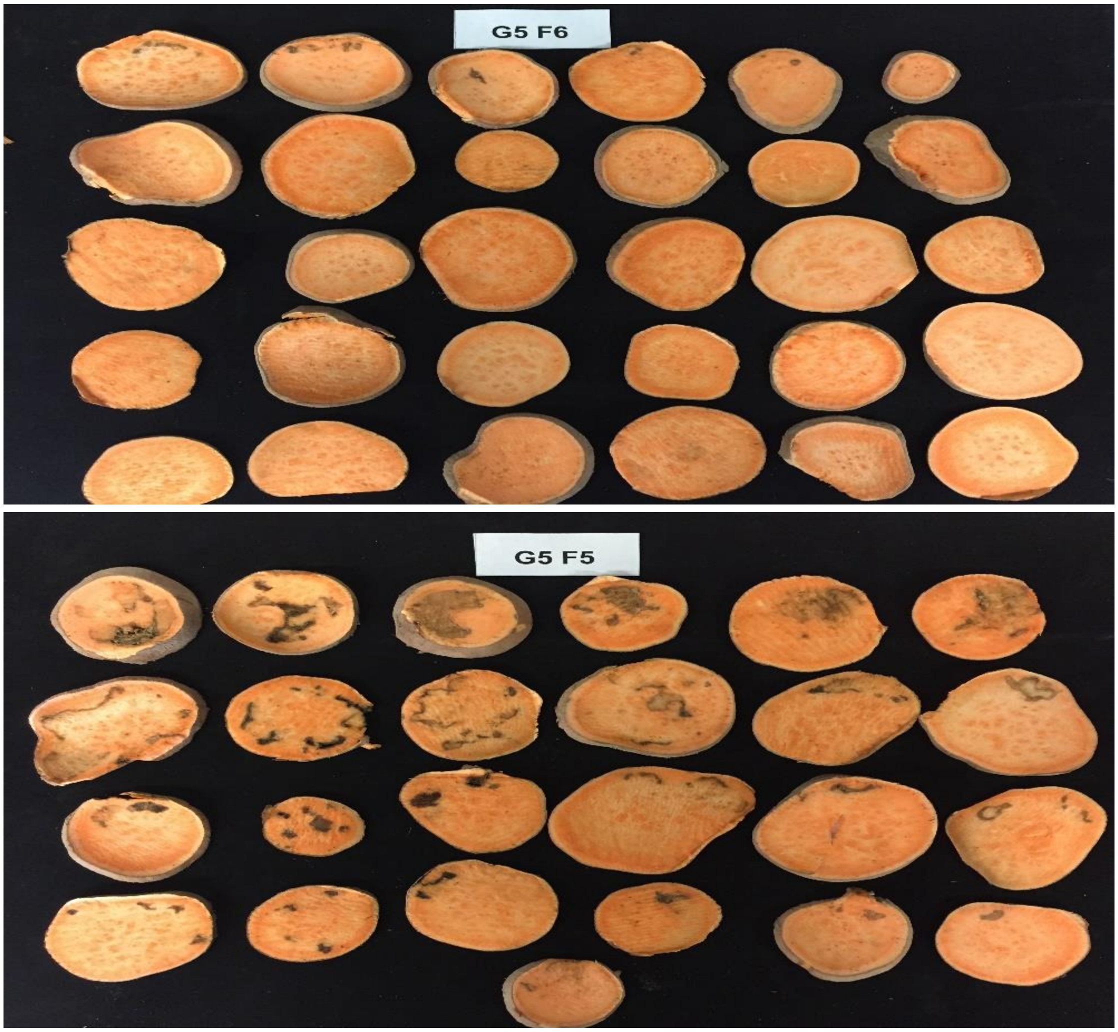

Figure 2. Sampled roots with a 5% (6/30) incidence of IN (Top) and very low severities of 2 or 3. In the bottom picture, IN incidence of 83% (25/30) with many roots having severities of 4 and 5.

Figure 3. Samples from Kinston 2017, showing the effects on IN incidence when curing at higher temperature (85ºF versus 75ºF) and longer curing durations (2 versus 1 week). Only roots exhibiting IN are shown from a 30-root sample.

CHAPTER II. EVALUATION OF INTERNAL NECROSIS IN ‘COVINGTON’ SWEETPOTATOES AT COMMERCIAL NORTH CAROLINA CURING AND STORAGE FACILITIES.

Fernando Montero de Espinosa Baselga, Jonathan R. Schultheis and Michael D. Boyette.

Two studies were conducted in 2016 and 2017 to evaluate the preharvest and postharvest practices of six North Carolina sweetpotato commercial growers and link the conditions encountered to the occurrence of Internal Necrosis (IN) in the sweetpotato cultivar Covington. Bins of sweetpotatoes were collected from each grower´s field the same day, then redistributed the following day so that each storage facility received a bin from each grower (6 total). This process included one harvest in 2016 and three harvests in 2017. Each harvest served as a replication. Temperature and relative humidity (RH) data were recorded from harvest until the last 30-root sample (4 total) was cut from each of the six bins at each location and the incidence of IN was recorded. Facility conditions were more important than grower practice both years. The effects of temperature and RH in , the storage rooms over various time periods (01-07, 01-14, 01-30 and 14-28 days after harvest, DAH) on IN occurrence were evaluated using Pearson correlation analysis. Maximum, minimum and average temperatures for 01-07 and 01-14 DAH had significant R-values greater than 0.6 in 2016, and between 0.1 and 0.3 in the 2016/2017 combined study. Thus, these variables were strongly correlated with IN occurrence during the first two weeks after harvest in storage. Relative humidity had little or no correlation with IN occurrence. Of the factors tested, temperature conditions during storage the first one or two weeks after harvest appear to

be highly influence subsequent IN incidence. Additional storage studies and modeling is warranted, especially temperature, to better predict IN occurrence.

INTRODUCTION

Sweetpotatoes are grown on about 9 million hectares with average yields of 14 tons/ha. (FAOSTAT, 2001). The production is mainly distributed in warm temperate and tropical countries. Southeast Asia, mainly China, is the primary producer of sweetpotatoes accounting for more than 80% of the world production. About 15% is grown in Africa and the rest of the world accounts for the remaining 5%, with the US accounting for about 1% of the world's sweetpotato production.

Curing is recommended within 1 to 2 hours after harvest and continued for 4 to 7 days at 80 to 85ºF and 90 to 95% relative humidity (RH) (NC Sweetpotato Commission, 2018; Edmunds et al., 2008; Loebestine and Thottappilly, 2009). Duration depends on the difference between root temperature (core temperature) and the curing temperature of the room (Edmunds et al., 2008). As roots are still metabolically active, respiring and transforming starch into sugar, heat is generated (respiration heat) and carbon dioxide is produced. Good airflow is necessary during curing to evacuate CO_2 and supply oxygen so it is uniformly distributed in the room. As little as one-half cubic foot of outside air per bushel per day is sufficient for proper ventilation. Humidity during the curing and storage process is also important. RH during curing should avoid the saturation point at 100% RH, where water could condense on top of the walls, bins or sweetpotatoes increasing the risk of postharvest diseases. Proper humidity benefits wound healing and also reduces the weight loss. After the curing process is completed, temperatures are reduced to 58ºF and RH is kept at 85% to 90% for long term root storage.

The Louisiana State University Agricultural Experiment Station released ‘Beauregard’, a copper skinned, orange-flesh variety that became accessible to growers in 1987 (Rolston et al., 1987). In only a few years ‘Beauregard’ dominated the North American commercial sweetpotato market. ‘Beauregard’ produced high yields and was resistant to fusarium wilt although very susceptible to root knot nematodes. ‘Beauregard’ dominated the US market until North Carolina (NC) State University released ‘Covington’ in 2005. When grown under NC´s weather conditions and the sandier soils, ‘Covington’ produces yields equal to ‘Beauregard’, and is typically 5 to 10 days later in maturity (Yencho et al, 2008). ‘Covington’ typically sizes its storage roots more evenly than ‘Beauregard’ resulting in fewer jumbo class roots and a higher percentage of number one roots.

In the early 2000´s the US experienced an increase in demand for sweetpotatoes and a need to meet consumer´s and industry´s preferences. The USDA reported that from 2000 to 2015 the average consumption of sweetpotatoes grew from 4.2 to 7.5 lbs per capita. (USDA ERS, 2017). Increasing demand for sweetpotatoes coincides with the emerging food trends in the past years. European markets´ demands for exotic and healthy food crops (superfoods) resulted in a direct impact on the increase of sweetpotato demand. Sweetpotatoes met most of these food trends and became a product with an increasing acceptance in national (US) and international markets.

To meet this demand, sweetpotato acreage harvested in the US has increased from 83,000 acres in 1999 to 163,300 acres in 2016 (FAOSTAT DATA, 2016). This increase was mainly attributed to the NC sweetpotato industry with improved postharvest technology for year-round sweetpotatoes coupled with ‘Covington’ having an excellent acceptance by growers and customers. North Carolina currently accounts for the 55-60% of the national production with 90,000 acres planted in 2017. (USDA ERS, 2017).

Although there have been improvements in the NC sweetpotato industry such as improved storage with negative horizontal ventilation (NHV) (Boyette, 2009) and new variety releases (Yencho et al., 2008; Rolston et al.,1987) there are new challenges to be overcome. One of them is a physiological disorder that was first reported in 2006 named Internal Necrosis (IN), mainly affecting ‘Covington’ (Jiang et al., 2015; Schultheis et al., 2009; Clark et al., 2013). Covington is the primary cultivar grown in NC and is susceptible to this disorder. Internal Necrosis is of concern in the NC sweetpotato industry and can cause significant dollar losses, especially if shipped loads are rejected domestically or internationally due to this problem. Research across several disciplines has been conducted as to the cause of IN; however, no study has been able to determine a definitive solution or to consistently reduce IN occurrence. Recent studies have evaluated insecticides (Jiang et al., 2015) pathogens (Golden Leaf Foundation, 2016; Lina Quesada, personal communication) herbicides (Beam et al., 2017) and ethylene (Jiang et al., 2015) as factors that can cause IN. Only when ethylene is applied to foliage prior to harvest as a defoliant has there been substantial increased response in IN (Dittmar et al., 2010; Arancibia et al., 2013; Beam et al., 2017; Clark et al., 2013; Jiang et al., 2015).

Various preharvest treatments in the field such as mowing or the use of low levels of chlorides in the formulation of commonly used fertilizers have been associated with less occurrence of IN (Montero de Espinosa et al., 2018). These factors in combination with reduced curing and low temperature durations of the roots after harvest (<80ºF) have lessened IN incidence and severity.

The purpose of this study was to evaluate the effects of curing and storage conditions (temperature and RH) in six commercial growers' facilities and relate their effects on the occurrence of IN. Thus, the goal of these studies was to use data obtained exclusively from commercial growers and facilities and determine which of these factors most contributed to IN. In addition, 10 temperature and RH variables were evaluated at various time intervals to determine those that best accounted for IN incidence.

METHODS

In order to evaluate the effects that commercial fields and storage facilities have on the incidence and severity of Internal Necrosis (IN) a two-year study (2016 and 2017) was conducted that involved six commercial sweetpotato producers. Three growers that had more frequent occurrence of IN were selected, while three growers that did not have an apparent problem with IN were selected. An initial study was conducted in 2016 in which a questionnaire was administered to determine what production and storage practices were followed by each producer and use this information to compare among growers if needed.

The growers that participated in 2016 were the same that participated in 2017, with one exception. There was one harvest time in 2016 and three harvest times in 2017 that served as replications. Three harvests in 2017 were incorporated into the study because the weather conditions in the field the day of harvest and during curing could have an impact on IN occurrence. The one harvest in 2016 was October 17, and the three harvests in 2017 were; early season (September 15), mid-season (October 15) and late season (October 23).

Roots were harvested by each grower for each harvest (4 total) from each of the six fields on the same day. Each grower provided six 20-bushel bins for the study for each harvest time

Each grower was randomly assigned a letter (U, V, W, X, Y or Z) to designate their field and storage facility (i.e. grower U on the tag meant that roots in those 20-bushel bins were from Grower U´s field. On the same tag, Facility (U, V, W, X, Y or Z) would specify where those bins were placed for curing and storage).

In order to track temperatures and RH during postharvest treatments, in 2016 three Hobo data loggers (Hobo® ONSET® UX100 -003, Onset Computer Corporation 470 MacArthur Blvd. Bourne, MA 02532) were placed inside three of the six bins. In 2017 the bins were stacked six high and Hobo data loggers were placed in each of the six bins.

Once the six 20-bushel bins were filled by each grower, the roots were transported the same day from each grower´s field and placed at a central location overnight. The bins were sorted so each grower would receive one bin from each grower´s field receiving a total of six bins (1 bin from the grower's own field and 5 bins from the other 5 growers' fields) the day after harvest.

In 2017 temperatures were evaluated between bulk bins within stacks to assess temperatures and RH at each bin height. If NHV was working properly, temperature differences between top and bottom bins in the stack should not exceed 3ºC (Boyette, 2009). A total of six Hobo data loggers per facility and harvest were placed in each bin to measure temperature and RH. A total of 18 Hobo data loggers per facility (6 at each harvest and facility) were used to determine the effect of IN incidence by temperature and RH for each bin. Hobo units recorded temperatures (ºF) and RH (%) every 30 minutes, starting the day of harvest until the last cutting sample day, approximately 180 DAH. The stack order of bins in 2017 was randomized and so the stacking order for each grower at each facility during each harvest was random (Figure 1).

To evaluate incidence of IN, a 30-root sample was taken at four different times after harvest from each bin at each facility, with a total of 120 roots collected per bin per harvest. Samples were taken starting 60 DAH, then 90, 120 and 180 DAH.

Roots were cut in thin slices (about 3-mm thick) starting from the stem end of the root until half or 2/3 of the root was sliced. When IN symptoms were present, the slice with the highest severity score (total surface of the slice with necrotic tissue) was recorded with the help of a grading card (2 being the lowest and 5 the highest) (Figure 2). Incidence of IN was calculated as the percentage of roots with any symptoms (2 to 5) of IN in a 30-root sample (4 total samples). Hobo data loggers were kept in the bins until the fourth sample was collected from each harvest. Three out of the 108 data loggers were lost or broken during harvest 3 in the 2017 study; Facility U- Grower V, Facility X-Grower Y, Facility Y-Grower X.

In 2016, a survey with 41 questions about the preharvest and postharvest practices at each grower´s field and facilities were given to each participant. The surveys were taken to see if there were common practices that could be associated with IN at preharvest (field practices) or postharvest (facility curing and storage). The survey was used to determine any obvious difference in practices among the growers. Preharvest practices such as mowing, fertilization, herbicides and insecticides or generation of the seed used for that year´s crop was some of the information gathered from the survey. The postharvest information such as curing time and temperature targeted, also provided information as to what the intended curing treatment was compared to what growers were achieving. For 2017, no survey was conducted.

Weather data from 2016 and 2017 the day of harvest and the first two weeks after harvest for each location (facility) was obtained by different weather stations (Appendix, Tables 1, 2, 3 & 4). Although these stations were not at the exact location where the roots were harvested and stored, proximity to the growers' locations provided a good reference for weather differences between harvests.

These data were analyzed using Proc Mixed, SAS/STAT software, Version 9.4M3 of the SAS System for Windows. The design was a 6x6 factorial with bins of sweetpotatoes from 6 growers cured in 6 different curing facilities. The experiment was replicated over time, with one harvest in a preliminary study in 2016 and 3 replications over time (harvest 1 – early season, 2 – mid season, and 3 – late season) were run consecutively in 2017. Bin temperature, RH and IN incidence were measured and analyzed. The Tukey-Kramer Method ($p<.05$) was used to test for differences between treatment means. The growers were not the same in both years, so 2016 data were analyzed separate from 2017. The 2016 study was a preliminary experiment and Grower*Facility was used as the error term for testing for grower and facility differences as there was no other random factor to use. The 2017 study had 3 full replications, run consecutively, and thus the analysis could test for grower*facility interactions.

Correlation analyses were run to determine if there was a significant correlation between bin temperature and/or RH during the first 30 days after harvest and the incidence of IN. In the 2016 study, measurements were obtained from 18 bins: 3 growers at 6 facilities. In 2017 measurements were obtained from 36 bins, 6 growers and 6 facilities, for each of the 3 replications. In 2017, three Hobo data loggers failed in 3 bins in the final rep, so the total N for the correlations was n=123. Correlations between the average temperature data at four different time periods were conducted (days 1 to 7 (01-07), days 1 to 14 (01-14), days 1 to 30 (01-30) and days 15 to 28 (15-28) after harvest). Considering previous studies at the research station facility

(Montero de Espinosa et al., 2018), these time periods were selected for these commercial studies. Ten variables were included in the analysis to better understand which factors have higher correlation with the incidence of IN at each of the four-time intervals. These variables for each time interval included; difference between maximum temperature and average temperature (Diff) throughout the selected periods, average of the maximum temperatures (MaxTemp), average of the minimum temperatures (MinTemp), average temperature (AvgTemp), average of the maximum relative humidity (MaxRH), average of the minimum RH (MinRH), days that temperature remained above 70ºF (DaysTempAbove70), days that temperature remained below 60ºF (DaysTempBelow60) and days that RH remained below 80% (DaysRHBelow80). By determining which values correlated best with IN incidence, these could be used to help growers avoid, reduce and predict IN occurrence.

RESULTS & DISCUSSION

*2016 Incidence*Grower*Facility analysis*

Determination was made as to whether facilities (postharvest conditions) have a greater effect on the incidence of IN than grower practices (preharvest conditions). Grower (Grower U, V, W, X, Y and Z) and facility (Facility U, V, W, X, Y and Z) were included in the study as independent variables. The dependent variable was obtained by the percentage incidence of IN averaged across four sample times as described earlier. To confirm that sampling results were consistent across time, the variable sample (1, 2, 3 and 4) was included in the analysis both years. Results confirmed that there is no sampling effect, meaning that IN incidence between sampling 60, 90, 120 and 180 DAH was similar. These results support studies published in 2018 where data showed that IN symptoms reaches a maximum by 30 DAH and remained similar thereafter (Dittmar et al., 2018).

Both variables (Grower and Facility) significantly impacted IN occurrence. However, Facility had a higher F-value than Grower (16.48 and 2.86, respectively) meaning that the variable Facility was more impactful on the response of IN occurrence than ‘Grower’ (Table 1). The interaction between Grower*Facility was used as the error term for testing for grower and facility differences as there was no other random factor to use. The conditions under which certain growers experienced a higher incidence of IN in some facilities and much lower in others was evaluated with a second analysis to determine the correlation of temperatures and RH with IN incidence.

Facilities U, X, Y and Z were the facilities with relatively high IN problems, with Facility Y having the most incidence of 63% (Table 2). In contrast Facility V and W had minimal incidences (2% and 3%, respectively), regardless of Grower, indicating the significant impact that facility has on minimizing IN occurrence. Even though IN incidence was 58% or more for five of the six growers in Facility Y, only 10% incidence occurred with Grower U roots in Facility Y. This indicates that there is/are grower factors or environmental conditions that can also influence IN incidence.

The different response in IN incidence from both Grower and Facility revealed that both preharvest and postharvest factors affect IN. There was variability of response from each individual grower´s storage roots (preharvest) within the same facility; i.e. Grower U roots (10%) versus 57% to 83% IN incidence from the other grower´s roots in the same Facility Y (Table 2). There were different effects that facilities (postharvest) had on the same grower´s roots; i.e. Grower Y root incidence in Facility W (1%) versus Facility U (55%). Although preharvest treatments in this study were not controlled, the postharvest temperatures and RH recorded at each facility were precise and help discern what postharvest differences may have influenced differences in IN incidence response between facilities (Figure 3). For example, Facility Y was above 85ºF for the first 7 DAH and reached 95ºF after 3 DAH, and RH was below 80% during the first 10 DAH. In contrast, Facility W temperatures were below 80ºF the entire time in storage and RH was usually above 80%. These temperatures and RH differences could explain the high IN incidence in Facility Y and low in Facility W.

Many preharvest agricultural practices have been reported to not cause IN occurrence (Jiang et al., 2015; Beam et al., 2017; Dittmar et al., 2018) while the use of ethephon prior to harvest has been reported to increase IN incidence (Dittmar et al., 2010; Arancibia et al., 2013; Clark et al., 2013). Though the survey information collected was not completed in total by all the growers, the surveys did confirm that ethephon was not applied in any of the fields where roots were sourced in which IN incidence was observed.

Other potential preharvest factors could influence postharvest response in a given facility. For example, the use of mowing or not mowing might predispose storage roots to postharvest conditions encountered after harvest. Based on the survey, mowing practice varied among growers. Grower X was the only grower that did not mow the vines prior to harvest. Grower U mowed only a few days ahead of harvest. Grower W only mowed the vine tips off about ten days before harvest. Growers Y and Z reported they mowed a week prior to harvest. The time from mowing to harvest and the method used, may be an important consideration and possible reason for the variability of the IN incidence response of different grower roots in the same facility (Montero de Espinosa et al., 2018).

2016 correlation analysis

The intervals 01-07 and 01-14 days after harvest showed temperature variables significantly correlated ($R > 0.60$) to the increase of IN incidence (Tables 3 and 4). Maximum and minimum temperatures (*MaxTemp, MinTemp*) during the first seven days affected IN incidence (both with a $P < 0.002$). Facility Y had the highest average maximum temperatures of 88ºF and the highest IN incidence of 55% (Figure 3, Table 5). Facilities V and W had 3% and 4% IN incidence and had an average maximum temperature (*MaxTemp*) of 75ºF and 73ºF, respectively (Figure 3) for the first seven days. Average temperatures (*AvgTemp*) were also correlated to the increase of IN during the first seven days after harvest ($P < 0.001$). Facility Y averaged 88ºF and had the highest IN incidence, followed by Facility Z with 80ºF (which had a moderate IN incidence) with the lowest being 73ºF in Facility W (Figure 3, Table 5) which had a very low IN incidence. Similar results for *Max, Min and AvgTemp* were obtained in the interval 01-14 days after harvest (Table 4).

DaysTempAbove70 was significant (P <0.041) for the 01-07 days interval (Table 4), but not the 01-14 days interval (Table 5). This likely occurred because most facilities were able to cool temperatures below 70ºF 5 to 8 days after harvest (Figure 3). However, Facilities X and Y remained above 70ºF for 13 and 9 days, respectively, and were the facilities with the highest incidence of IN (24% and 55%, respectively) (Table 5). This variable is not as good of an indicator of IN occurrence as the *Max, Min and AvgTemp*. A 70ºF threshold might be too low to result in substantial IN incidence. Temperatures as low as 75ºF were observed to result in IN incidence but incidence was much lower than when temperatures exceeded 80ºF (Golden Leaf Foundation, 2016). Although the days above 70ºF were higher in Facility X (13 days), the IN incidence recorded at this facility was 38% lower than in Facility Y, which was exposed to temperatures above 70ºF for 9 days. In this case, higher temperatures (81ºF) in Facility Y for 9 days had a much higher impact than the exposure of 13 days to 76ºF in Facility X. Thus, this measure may not accurately reflect IN incidence.

None of the RH variables showed significant correlations at the P=.05 level during the first seven or fourteen DAH (Tables 3 and 4). Relative humidity in Facility Y remained lower (79%) than what is recommended in the sweetpotato industry (Boyce et al., 1956; Boyette and Stewart, 1994; Nabubuya et al., 2017; Boyette, 2009) and had high levels of IN (Table 3). However, RH varied considerably from recommended levels and did not correlate well with IN incidence. Rather it seems like temperatures during the first fourteen DAH are the main factor influencing IN occurrence as RH variables were not good indicators of IN. Further research should evaluate the influence of low RH during the curing process as it´s been shown to affect the physiology of the roots (Boyce et al., 1956; Jones and Rosa, 1928; Nabubuya et al., 2017; Huang et al., 2014).

The variables 01-30 and 15-28 days after harvest didn´t show any significant correlation with the incidence of IN at the P=0.05 level (data not shown). These two intervals contained a substantial amount of temperature and RH data points where the temperatures were below 60ºF and RH was mostly around the 85%. The lack of significance in these two intervals provides evidence that IN occurrence is critical during the first fourteen days after harvest. The IN incidence response found in commercial facilities agrees with controlled temperature studies at the research station (Montero de Espinosa et al., 2018.)

*2017 Incidence*Grower*Facility analysis*

As in 2016, a ProcMixed analysis with IN incidence as the dependent variable was used to evaluate differences between Grower and Facility. The three harvests were not included as fixed effects, rather, they were used as replicates. The IN incidence recorded in harvest (replication) 1 and 2 were higher than in harvest 3 (data not shown). Differences in IN incidence between growers were not significant (P<0.0735); however, facility was significant with a P=0.0133 (Table 6). The interaction of these two variables was not significant. Less significance for the main effects and the interaction in 2017 than in 2016 was likely due to the lower IN incidence in 2017. When compared to the 2016 (Table 2) IN incidence was; U (36%), V (3%), W (4%), X (25%) Y (63%) and Z

(17%), while there was a decrease of IN occurrence in these facilities in 2017 (Table 7) (average of three harvests); U (5%), V (2%), W (3%), X (13%), Y (9%) and Z (4%). The grower main effect was not significantly different across the six growers with averages ranging from as low as 2% (Grower Y) as high as 11% (Grower Z) (Appendix, Table 5).

The variability of IN occurrence between harvests remains unclear. However ambient temperatures the day of harvest and for the first fourteen DAH may be an important factor to consider. Ambient temperatures varied between harvests; Harvest 1 (September 14) at facilities Y, V, X and Z averaged 75ºF to 78ºF during the first fourteen DAH, and facilities U and W had outside average temperatures 65 to 75ºF throughout the same period. Harvest 2 (October 4) was warmer than Harvest 1 (71ºF to 80ºF versus 67ºF to 78ºF, respectively) the first seven to ten DAH in Facility U, W and (71ºF to 83ºF versus 75ºF to 76ºF, respectively) in Facility Y. (Appendix, Tables 1, 2, & 3). Weather temperatures during Harvest 3 (October 22) were cooler (66ºF) than at harvests 1 and 2 in all locations. After harvest 3, weather temperature also remained low; below or at 60ºF the third day after harvest until the end of the second week after harvest. The temperature differences between harvests may play an important role since facility managers participating in the study reported that cooler temperatures during the days of harvest will directly affect the efficiency of cooling the rooms after the curing process is achieved. Ambient temperatures at harvest and the first two weeks after harvest may have contributed to the general differences in IN occurrence between harvests or replications.

Two-year combined correlation study

For the combined study, IN incidences were averaged across the four replications (Harvests) and the overall incidence in this study was lower than in 2016. The highest incidence was Facility Y (16%), followed by Facility X (15%) with the remaining facilities between 2% and 8 % IN (Table 8).

A consistent correlation occurred between the incidence of IN and the temperature variables in storage (*Max, Min, AvgTemp)* during the first seven (01-07) and fourteen days (01-14) when all four harvests were combined for 2016 and 2017 (Table 9, 10). The R-values are much smaller compared to 2016 as the R-values ranged from 0.24 to 0.30. This is likely to the high variability between replications in the two-year combined study. Even though R values in this analysis versus 2016 are lower, these data indicate that Facility temperature plays an important role in IN incidence. This agrees with observations made in a preliminary study in 2016 (Golden Leaf Foundation, 2016) and controlled storage room studies (Montero de Espinosa et al., 2018).

The first 01-07 days, facilities with the highest IN incidence showed maximum temperatures were 78ºF to 82ºF (Table 8). Incidence in facilities Y, X and U were 16, 15 and 8%, respectively. The maximum temperatures ranged from 74ºF to 78ºF in the facilities with low incidence (2 to 6 %). Minimum temperature (*MinTemp*) and average temperature (*AvgTemp*) during the first 01-07 and 01-14 days after harvest were also significant (Table 9). One outlier was Facility X which had a maximum of 78ºF and 15% IN incidence. Average and maximum temperatures were generally higher than in most facilities and may have accounted for the higher IN incidence compared with the other facilities.

The small differences between the maximum temperatures across the six facilities coupled with average and minimum temperatures, shows that small variations in temperature can have a great impact on IN occurrence during the first fourteen days after harvest (Table 8).

Days of exposure to temperatures above 70ºF (*DaysTempAbove70*) was significantly correlated with the incidence of IN, only during the first seven days after harvest (01-07) (Tables 9, 10 and 11). Small differences between facilities with longer exposure to temperatures above 70ºF (6.6 to 7 days) versus shorter exposure (5.1 to 5.6) shows the difference a day makes when temperatures are above 70ºF as the former increases IN occurrence (Table 8). In a recent study, exposure of storage roots for four days (½ week) to either 75 or 85ºF resulted in significantly lower incidence of IN than those exposed to the same temperatures for seven or fourteen days (Montero de Espinosa et al., 2018).

Relative humidity variables seemed to have a minimal impact on IN occurrence as days RH below 80% (*DaysRHBelow80*) was the only significant RH variable during the first seven DAH ($P<0.019$) (Table 9). Facility W had the highest number of days below 80% RH (1.1) followed by Facility V (0.7) (Table 8). Both of these facilities had the lowest IN incidence for the first seven days (01-07). Although there appeared to be some connection with RH and IN incidence, variables were not significant for the 01-14 (Table 10), 15-28 DAH (data not shown) and the 01-30 (Table 11) time intervals. Thus, RH had limited impact on IN incidence.

During the 01-30 period (Table 11), the difference between the maximum and average temperature (*Diff*), minimum temperature (*MinTemp*) and average temp (*AvgTemp*) were significant. It is important to point out the potential importance of the *Diff* variable since it could be a good indicator of how a facility cools during the night. *Dif*f R-value is a negative number (-0.187) thus, the lower this value is, the more IN incidence occurs. Facilities with lower *Diff* value are maintained average temperatures close to the maximum value during the entire day. Facilities U, X and Y had 2 degrees of difference compared to the 4, 3 and 4 degrees recorded in facility V, W and Z, respectively (Table 8).

In conclusion, these studies show that the Facility has a more important role in the occurrence of IN than Grower practice or preharvest conditions. Temperature is a key factor that impacts the occurrence of IN. In addition, the first seven days after harvest is the most critical time period that influence IN incidence. The variables maximum, minimum and average temperature could potentially be used in the future as an important indicator of IN occurrence risk. Additional storage studies and modeling is warranted, especially temperature, to better predict IN occurrence.

REFERENCES

Arancibia, R.A., J.L. Main, and C.A. Clark. 2013. Sweetpotato tip rot incidence is increased by preharvest applications of ethephon and reduced by curing. HortTechnology 23:288–293.

Beam, S.C., K.M. Jennings, D.W. Monks, J.R. Schultheis, and S. Chaudhari. 2017. Influence of herbicides on the development of internal necrosis of sweetpotato ((Ipomoea batatas (L.)(Lam). Weed Technol. 31:863–869.

Boyette, M.D. 2009. The investigation of negative horizontal ventilation for long-term storage of sweetpotatoes. American Soc. of Ag. and Bio. Engineers. Vol. 25(5): 701-708.

Boyette, M. D., and H. E. Stewart. 1994. Horizontal ventilation for long-term storage of sweetpotatoes. ASAE Paper No. 946583. St. Joseph, Mich.: ASAE.

Boyce D.E., S.W. Marguerite and D.D. Kenneth. 1956. Biological and biochemical effects of storage humidity on sweet potatoes. Biological Bioscience Branch, Agricultural Marketing Service, USDA, Beltsville, Md.

Clark, C.A., D. Ferrin, T. Smith and G. Holmes., 2013. Compendium of sweetpotato diseases, pests, and disorders. The American Phytopathological Society. 2nd ed. p.144.

Dittmar, P.J., K.M. Jennings, D.W. Monks, and J.R. Schultheis. 2010. Determining the effect of ethylene on internal black marbling expression in sweetpotato. HortScience 45:488–489 (Abstr.).

Dittmar, PJ., J.R. Schultheis, K.M. Jennings, D.W. Monks, S. Chaudhari, S. Meyers, and C. Jiang. 2018. Effect of cultivar, ethephon, flooding and storage duration on sweetpotato internal necrosis. HortTechnology 28(3):246-250.

Edmunds, B.A, M. Boyette, C.A. Clark, D. Ferrin, T. Smith, and G. Holmes. 2008. Postharvest handling of sweetpotatoes. N.C. Cooperative Extension Service. p.12. Raleigh, NC.

Golden Leaf Foundation, 2016. Determining the cause and control of internal necrosis in sweetpotatoes. Project number 14-147 final project, 301 North Winstead Avenue. Rocky Mount, NC 27804.

Huang, C. L., W. C. Liao, C. F. Chan, Y. C. Lai, 2014. Storage performance of Taiwanese sweetpotato cultivars. J. Food Sci. 51(12), 4019–4025.

Jiang, C., P.Perkins-Veazie, S.M. Blankenship, M.D. Boyette, Z. Pesic-VanEsbroeck, K.M. Jennings, and J.R. Schultheis. 2015. Occurrence, severity, and initiation of internal necrosis in 'Covington' sweetpotato. HortTechnology 25:340 348.

Jones, H.A., and J.T. Rosa.1928. Truck Crop Plants. McGraw-Hill, New York.

Loebestine, G. and G. Thottappilly (eds.). 2009. The Sweetpotato. DOI 10.1007/978-1-4020 9475-0 20, Springer Science+Business Media B.V.

Montero de Espinosa, F., J.R. Schultheis, and M.D. Boyette. 2018. Preharvest and postharvest effects on internal necrosis incidence and severity in 'Covington' sweetpotato, 2016 and 2017. HortScience 53(9):Supplement (abstr.) In press.

Nabubuya A, A. Namutebi, Y. Byaruhanga, J. Narvhus, and T. Wicklund. 2017. Influence of development, postharvest handling, and storage conditions on the carbohydrate components of sweetpotato (*Ipomoea batatas (L.) (Lam*) roots. Food Sci. Nutr. 5:1088–1097.

Rolston, L.H., C.A. Clark, J.M. Cannon, W.M. Randle, E.G. Randle, E.G. Riley, P.W. Wilson, and M.L. Robbins. 1987. 'Beauregard' sweetpotato. HortScience 22:1338–1339.

Schultheis, J.R., Z. Pesic-VanEsbroeck, K.M. Jennings, P.J. Dittmar, and A.C. Thornton. 2009. Effects of environmental stress and pathogens on the internal mottling and end rots of sweetpotato in new commercial varieties ('Hatteras' and 'Covington') and established commercial varieties ('Beauregard' and 'Carolina Rudy'). North Carolina sweetpotato research and extension reports 2009. NC State Univ., Raleigh, NC.

Yencho, G.C., K.V. Pecota, J.R. Schultheis, Z. Pesic-Vanesbroeck, G.J. Holmes, B.E. Little, A.C. Thornton, and V. Truong. 2008. 'Covington' sweetpotato. HortScience 43(6):1911-1914.

[North Carolina Sweetpotato Commission]. 2018. https://ncsweetpotatoes.com/sweet-potato-industry/

[USDA-NASS] 2007. United States Standards for Grades of Sweetpotatoes. http://www.ers.usda.gov/Publications/vgs/Tables/Swpot.pdf.

[USDA-ERS] 2017. Parr, B., and T. Minor. 2018. "Vegetables and Pulses Yearbook, Supply and Utilization Data (Machine readable-CSV)," Economic Research Service, U.S. Department of Agriculture.

https://www.ers.usda.gov/topics/crops/vegetables-pulses/commodity-highlights.aspx

[FAOSTAT] 2001. FAO Statistical Database.

URL http://faostat.fao.org/

[FAOSTAT] 2008. FAO Statistical Database.

URL http://faostat.fao.org/

[FAOSTAT] 2016. FAO Statistical Database.

URL http://faostat.fao.org/

Table 1. Type 3 tests fixed effects, 2016.

Effect	Num DF	Den DF	F Value	Pr > F
Grower	5	25	2.86	0.0357
Facility	5	25	16.48	<.0001

Table 2. Average percentage of IN for each grower (column) and each facility (row), 2016.

	Grower						
Facility	U	V	W	X	Y	Z	Avg.
U	19[z]	17	39	23	55	10	27
V	4	0	1	2	4	2	2
W	4	5	3	5	1	2	3
X	16	11	20	22	48	33	25
Y	10	74	58	83	82	72	63
Z	6	9	9	30	39	7	16
Avg.	10	19	21	27	39	21	
LSD[Y] (0.05)				24			

[Z] Incidence of IN from the 180 sampled roots from each grower´s bin.
[Y] Pair wise comparisons for significance for each Grower and Facility.

Table 3. Pearson correlation coefficient, N=18 for 01 – 07 DAH, 2016.

	Diff	Max Temp	Min Temp	Avg Temp	MaxRH	MinRH	AvgRH
(R) Value[Z]	0.217	0.673	0.612	0.637	-0.407	-0.168	-0.380
P-Value	0.771	0.002	0.002	0.001	0.193	0.792	0.312

	DaysTemp Above70	DaysRH Below80	DaysTemp Below60
(R) Value	0.486	0.402	NA[Y]
P-Value	0.041	0.098	NA

[Z] The value shows the linear relationship between the variable selected and the % IN Incidence that the variable accounts for. A negative number shows an inverse relationship.

[Y]NA means Not Applicable.

Table 4. Pearson correlation coefficient, N=18 for 01-14 DAH, 2016.

	Diff	Max Temp	Min Temp	AvgTemp	MaxRH	MinRH	AvgRH
(R) Value[Z]	0.074	0.672	0.669	0.694	-0.322	-0.067	-0.252
P-Value	0.772	0.002	0.002	0.001	0.193	0.792	0.312

	DaysTemp Above70	DaysRH Below80	DaysTemp Below60
(R) Value	0.409	0.169	-0.183
P-Value	0.092	0.503	0.467

[Z] The value shows the linear relationship between the variable selected and the % IN Incidence that the variable accounts for. A negative number shows an inverse relationship.

Table 5. Internal necrosis incidence, temperature and RH variables during the intervals 01-07 and 01-14 DAH, 2016 and 2017.

Facility	%IN	MaxTemp	AvgTemp	Diff (Max-Avg)	MinTemp	MaxRH	MinRH	Avg RH	Days Temp Above 70	Days RH Below 80	Days Temp Above 70
					Days 01-07						
U	17	80	75	5	72	86	69	80	6.3	1.7	0
V	3	75	72	3	69	82	66	76	5	2.2	0
W	4	73	71	3	68	87	74	83	5.7	1	0
X	24	78	73	5	69	88	73	82	7	0.7	0
Y	55	88	85	4	81	83	71	79	7	2.7	0
Z	14	80	78	3	75	91	78	87	7	0.7	0
					Days 01-14						
U	17	72	69	3	67	87	74	82	6.3	1.7	0
V	3	71	67	4	63	80	64	73	5.3	6	0
W	4	69	67	2	65	89	75	83	6.7	1	0.7
X	24	76	72	4	68	86	72	81	12.7	0.7	0
Y	55	81	77	4	73	84	71	79	9	3.3	0
Z	14	74	71	3	68	90	74	83	8	1.3	0

Table 6. Type 3 tests of fixed effects, 2017.

Effect	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Grower	5	70	2.12	0.0735
Facility	5	70	3.12	0.0133
*Grower*Facility*	25	70	0.32	0.9990
Sample	3	291	0.39	0.7583
*Grower*Sample*	15	291	1.15	0.3141
*Facility*Sample*	15	291	1.34	0.1763

Table 7. Average percentage of IN for each grower (column) at each facility (rows) after three harvests, 2017.

	Grower						
Facility	U	V	W	X	Y	Z	Avg.
U	2[Z]	3	10	1	1	15	5 ab
V	2	6	1	2	1	2	2 b
W	1	4	4	5	1	4	3 b
X	9	20	15	8	6	16	12 a
Y	10	8	12	4	5	17	9 ab
Z	3	4	8	1	0	10	4 ab
Avg.	4 a[Y]	7 a	8 a	3 a	2 a	11 a	

[Z] Average incidence of IN from the 180 sampled roots from each of the grower´s bin.
[Y] Significant at the <.05 level when letters differed within Facility or Grower.

Table 8. Internal necrosis incidence, temperature and RH variables during the intervals 01-07, 01-14 and 01-30 DAH for each facility, 2016 and 2017.

Facility	% IN	MaxTemp	AvgTemp	Diff (Max-Avg)	MinTemp	Max RH	MinRH	AvgRH	Days Temp Above 70	Days RH Below 80	Days Temp Above 70
Days 01-07											
U	8	82	80	3	76	93	76	87	6.7	0.3	0.0
V	2	78	75	4	71	90	74	84	5.5	0.7	0.0
W	3	74	70	4	67	86	72	80	5.1	1.0	0.4
X	15	78	76	2	74	95	85	92	7.0	0.1	0.0
Y	16	81	79	3	75	92	79	87	6.6	0.5	0.0
Z	6	78	74	5	70	91	74	85	5.6	0.4	0.3
Days 01-14											
U	8	75	73	2	71	89	77	84	9.2	2.1	0.6
V	2	76	71	4	67	88	72	81	8.8	1.6	0.0
W	3	72	69	3	65	86	73	80	8.5	2.4	0.6
X	15	75	73	2	71	94	86	91	11.8	0.1	0.0
Y	16	74	71	2	69	91	81	87	7.5	0.7	0.8
Z	6	74	71	4	67	90	77	85	8.9	1.5	1.2
Days 01-30											
U	8	69	67	1.9	64	87	75	82	11.7	6.0	4.8
V	2	70	66	3.8	62	85	71	79	13.0	7.0	5.9
W	3	69	66	2.9	63	84	72	79	12.6	6.9	3.9
X	15	68	67	1.5	65	92	84	89	14.7	2.0	8.0
Y	16	65	63	1.8	61	91	84	88	7.5	0.7	15.0

Table 9. Pearson correlation coefficient, N=123 for 01-07 DAH, 2016 – 2017 combined.

	Diff	MaxTemp	MinTemp	AvgTemp	MaxRH	MinRH	AvgRH
(R) Value[Z]	-0.119	0.241	0.306	0.270	-0.149	-0.087	-0.050
P-Value	0.189	0.007	0.006	0.003	0.100	0.339	0.581

	DaysTemp Above70	DaysRH Below80	DaysTemp Below60
(R) Value	0.197	0.211	-0.123
P-Value	0.029	0.019	0.176

[Z] The value shows the linear relationship between the variable selected and the % IN Incidence that the variable accounts for. A negative number shows an inverse relationship.

Table 10. Pearson correlation coefficient, N=123 for 01-14 DAH, 2016 – 2017 combined.

	Diff	MaxTemp	MinTemp	AvgTemp	MaxRH	MinRH	Avg RH
(R) Value[Z]	-0.103	0.247	0.295	0.284	-0.127	0.016	-0.058
P-Value	0.257	0.006	0.009	0.002	0.163	0.858	0.525

	DaysTemp Above70	DaysRH Below80	DaysTemp Below60
(R) Value	0.197	0.114	-0.102
P-Value	0.063	0.211	0.264

[Z] The value shows the linear relationship between the variable selected and the % IN Incidence that the variable accounts for. A negative number shows an inverse relationship.

Table 11. Pearson correlation coefficient, N=123 for 01-30 DAH, 2016 – 2017 combined.

	Diff	MaxTemp	MinTemp	AvgTemp	MaxRH	MinRH	AvgRH
(R) Value[Z]	-0.187	0.130	0.225	0.182	-0.052	0.108	0.022
P-Value	0.038	0.152	0.012	0.044	0.565	0.233	0.814

	DaysTemp Above70	DaysRH Below80	DaysTemp Below60
(R) Value	0.093	0.022	-0.057
P-Value	0.305	0.812	0.530

[Z] The value shows the linear relationship between the variable selected and the % IN Incidence that the variable accounts for. A negative number shows an inverse relationship.

Harvest 1 Facility “U” – Grower V Bin 6 (Top)	Harvest 2 Facility “U” – Grower Y Bin 6 (Top)	Harvest 3 Facility “U” – Grower Z Bin 6 (Top)
Harvest 1 Facility “U”– Grower W Bin 5	Harvest 2 Facility “U” – Grower V Bin 5	Harvest 3 Facility “U”– Grower Y Bin 5
Harvest 1 Facility “U” – Grower Y Bin 4	Harvest 2 Facility “U” – Grower U Bin 4	Harvest 3 Facility “U” – Grower X Bin 4
Harvest 1 Facility “U” – Grower U Bin 3	Harvest 2 Facility “U” – Grower Z Bin 3	Harvest 3 Facility “U”– Grower W Bin 3
Harvest 1 Facility “U” – Grower Z Bin 2	Harvest 2 Facility “U” – Grower X Bin 2	Harvest 3 Facility “U” – Grower V Bin 2
Harvest 1 Facility “U” – Grower X Bin 1 (Floor)	Harvest 2 Facility “U”– Grower W Bin 1 (Floor)	Harvest 3 Facility “U” – Grower U Bin 1 (Floor)

Figure 1. Example of the 18 bins (6 per Harvest) cured and stored in one Facility “U” in separate rooms, where each growers´ bin occupied a different stack position at each harvest. i.e. Grower W in harvest 1 was at the 5th level from the floor while for harvest 2, Grower W was on the floor (Bin 1) and harvest 3 Grower W was at the 3rd level from the floor.

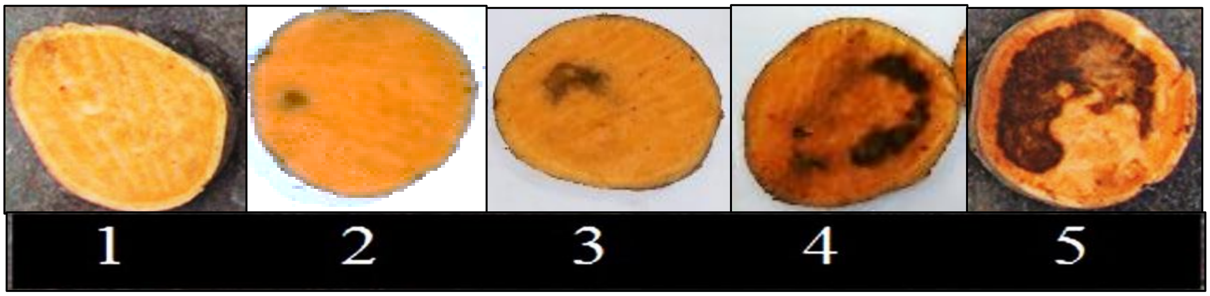

Figure 2. Grading cards used for rating Internal Necrosis severity. 1 = no internal necrosis incidence, 2 = least severe and still marketable root, < 5% necrotic, 3 = darker necrotic tissue with limited necrotic area still marketable, 5 to 20% necrotic, 4 = Necrotic tissue covers 21-60% of the sampled root, darker color, not marketable, 5 = Necrotic tissue covers > 60% of the sample, dark and not marketable.

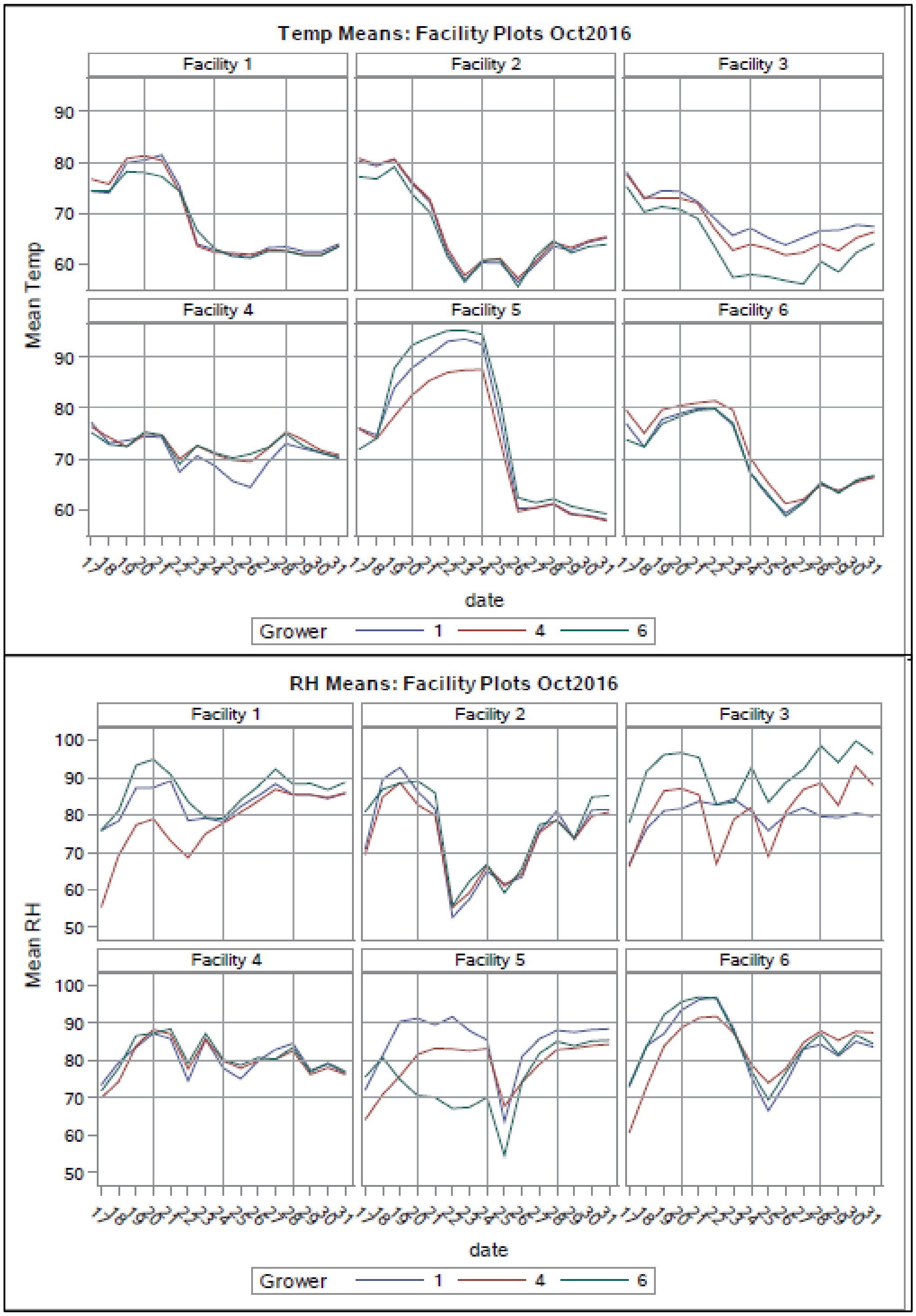

Figure 3. Average temperatures (top) and RH (bottom) of the three grower´s bins at each of the six facilities during the first 14 DAH. 2016. Numbers 1, 2, 3, 4, 5 and 6 refer to the letters U, V, W, X, Y and Z, respectively for each of the three growers; (1=U, 4=X, 6=Z).

APPENDICES

APPENDIX A. CHAPTER I

Table 1. Average temperatures for each temperature treatment duration (weeks) recorded at the research station in Clinton for the three studies in 2016.

	Warren Farms			*Kinston*			*Hilltop Farms*		
				Room 58 ºF [z]					
Harvest	October 3	Temp ºF	RH%	October 19	Temp ºF	RH%	November 2	Temp ºF	RH%
1/2week	October 7	63.2	81.2	October 22	59.6	83.4	November 5	59.6	84.5
1 week	October 10	66.8	78.6[y]	October 26	59.5	84.5	November 9	59.6	85.1
2 weeks	October 17	65.2	82.9	November 2	59.5	84.1	November 16	59.2	85.4
3 weeks	October 24	61.8	83.2	November 9	59.6	85.2	November 23	59.1	85.5
5 weeks	Nov 7	60.9	84.1	November23	59.1	85.5	December 7	59.1	86.2
				Room 75 ºF					
Harvest	October 3	Temp ºF	RH%	October 19	Temp ºF	RH%	November 2	Temp ºF	RH%
1/2week	October 7	74.8	88.6	October 22	76.5	85.9	November 5	74.8	86.1
1 week	October 10	65.0	80.4	October 26	75.4	85.6	November 9	74.7	86.4
2 weeks	October 17	65.1	85.6	November 2	75.2	86.2	November 16	74.7	86.6
3 weeks	October 24	70.4	86.0	November 9	75.0	86.2	November 23	74.9	86.5
5 weeks	Nov 7	72.7	86.9	November 23	75.0	86.5	December 7	76.8	87.1
				Room 85 ºF					
Harvest	October 3	Temp ºF	RH%	October19	Temp ºF	RH%	November 2	Temp ºF	RH%
1/2week	October 7	81.6	90.2	October 22	81.9	85.4	November 5	81.8	85.7
1 week	October 10	69.8	79.9	October 26	82.0	85.8	November 9	81.8	86.4
2 weeks	October 17	81.9	84.9	November 2	82.0	85.8	November 16	81.8	86.3
3 weeks	October 24	82.0	85.4	November 9	81.9	86.4	November 23	81.9	86.7
5 weeks	Nov 7	81.9	85.9	November 23	81.9	86.1	December 7	81.9	87.0

[Z] Data recorded with three Hobo® ONSET® UX100 -003 units placed in each temperature treatment room.

[Y] Hurricane Matthew affected temperatures and relative humidity due to a power outage at the research station. The shaded areas indicate the affected times.

Table 2. Average temperatures for each temperature treatment duration (weeks) recorded at the research station in Clinton for the three studies in 2017.

	Warren Farms			Kinston		
			Room 58 ºF [z]			
Harvest	September 29	Temp ºF	RH%	September 22	Temp ºF	RH%
1/2 week	October 3	61.7	78.4	September 26	60.8	79.8
1 week	October 6	63.0	81.2	September 29	61.7	80.4
2 weeks	October 14	60.1	80.6	October 6	62.7	81.6
			Room 75 ºF			
Harvest	September 29	Temp ºF	RH%	September 22	Temp ºF	RH%
1/2 week	October 3	77.4	81.0	September 26	75.2	81.6
1 week	October 6	76.8	83.6	September 29	76.6	83.0
2 weeks	October 14	76.8	87.2	October 6	77.6	87.0
			Room 85 ºF			
Harvest	September 29	Temp ºF	RH%	September 22	Temp ºF	RH%
1/2 week	October 3	83.0	91.2	September 26	84.0	87.3
1 week	October 6	83.0	91.5	September 29	84.0	89.2
2 weeks	October 14	84.0	92.6	October 6	83.7	90.8
			Room 95 ºF			
Harvest	September 29	Temp ºF	RH%	September 22	Temp ºF	RH%
1/2 week	October 3	95.2	98.5	September 26	93.3	98.2
1 week	October 6	95.2	97.5	September 29	95.2	98.8
2 weeks	October 14	95.3	96.9	October 6	95.3	97.8

[Z] Data recorded with three Hobo® ONSET® UX100 -003 units placed in each temperature treatment room.

Table 3. Weather data from the Horticultural Crops Research Station in Clinton NC. Data used for the Warren Farms study location[z]

Horticultural Crops Research Station , Clinton NC Warren Farms Study Location			
Dates	Event	2m [Y] Mean Temp (°F)	1m Daily Precip. (in)
2016			
06/11	Transplant		
08/01 – 08/15		82	0.16
08/16 – 09/01		81	0.11
09/02 – 09/15		76	0.30
09/16	Mow	75	-
09/17 – 09-/24		75	0.32
09/25 – 10/02		75	0.37
10/03	Harvest	71	-
2017			
05/31	Transplant		
08/01 – 08/15		79	0.23
08/16 – 08/31		79	0.13
09/01 – 09/14		72	0.35
09/15	Mow	78	0.01
09/16 – 09/28		76	0.01
09/29	Harvest	71	-

[Z] Data provided by the State Climate Office, 1005 Capability Drive, NC State University.
[Y] Height from the ground level where temperature and precipitation were recorded at the weather station.

Table 4. Weather data from the Cunningham Research Station in Kinston NC. Weather station on farm[Z]

Cunningham Research Station, Kinston NC, Kinston Study Location			
Dates	Event	2m [Y] Mean Temp (°F)	1m Daily Precip. (in)
2016			
06/17	Transplant		
08/01 – 08/15		83	0.14
08/16 – 09/01		81	0.17
09/02 – 09/15		77	0.34
09/16 – 09/25		76	0.40
09/26	Mow	71	-
09/27 – 10-/11		70	0.72
10/12 – 10/18		67	-
10/19	Harvest	76	-
2017			
06/01	Transplant	78	-
08/01 – 08/15		79	0.16
08/16 – 08/31		79	0.06
09/01 – 09/07		75	0.43
09/08	Mow	66	-
09/09 – 09/21		72	0.06
09/22	Harvest	76	0.01

[Z] Data provided by the State Climate Office, 1005 Capability Drive, NC State University.
[Y] Height from the ground level where temperature and precipitation were recorded at the weather station.

Table 5. Weather data from Erwin, Harnett County NC. Data used for the Hilltop Farms study location[Z].

Erwin NC, Harnett County, Hilltop Farms Study			
Dates 2016	Event	2m [Y] Mean Temp (°F)	1m Daily Precip. (in)
06/28	Transplant		
08/01 – 08/15		83	0.12
08/16 – 09/01		81	0.28
09/02 – 09/15		77	0.91
09/16 – 09/30		76	0.84
09/30 – 10/20		68	0.56
10/21	Mow	74	-
10/22 – 11/01		63	0.07
11/02	Harvest	64	-

[Z] Data provided by the State Climate Office, 1005 Capability Drive, NC State University.
[Y] Height from the ground level where temperature and precipitation were recorded at the weather station.

APPENDIX B. CHAPTER II

Table 1. "Facility Y", average temperatures recorded for the first two weeks after harvest at the Cunningham Research Station, Kinston, NC, 2016 and 2017.

2016		2017					
AVG. TEMP	H1	AVG. TEMP	H1	AVG. TEMP	H2	AVG. TEMP	H3
70	10/17/16	77	9/14/17	68	10/04/17	67	10/22/17
72	10/18/16	76	09/15/17	71	10/05/17	70	10/23/17
76	10/19/16	76	9/16/17	71	10/06/17	69	10/24/17
73	10/20/16	74	9/17/17	74	10/07/17	57	10/25/17
70	10/21/16	74	9/18/17	80	10/08/17	52	10/26/17
56	10/22/16	74	9/19/17	79	10/09/17	55	10/27/17
55	10/23/16	76	9/20/17	83	10/10/17	61	10/28/17
65	10/24/16	77	9/21/17	80	10/11/17	56	10/29/17
55	10/25/16	76	9/22/17	76	10/12/17	49	10/30/17
-	10/26/16	75	9/23/17	70	10/13/17	53	10/31/17
-	10/27/16	78	9/24/17	69	10/14/17	59	11/01/17
-	10/28/16	72	9/25/17	73	10/15/17	66	11/02/17
-	10/29/16	68	9/26/17	63	10/16/17	65	11/03/17
-	10/30/16	68	9/27/17	54	10/17/17	63	11/04/17

Table 2. “Facility U” 2017 and “Facility W” 2016/17, average temperatures recorded for the first two weeks after harvest at the Finch´s weather station in Wayne County, NC.

2016		2017					
AVG. TEMP	H1	AVG. TEMP	H1	AVG. TEMP	H2	AVG. TEMP	H3
69	10/17/16	67	9/14/17	67	10/04/17	66	10/22/17
71	10/18/16	65	09/15/17	71	10/05/17	72	10/23/17
73	10/19/16	67	9/16/17	71	10/06/17	65	10/24/17
72	10/20/16	67	9/17/17	74	10/07/17	56	10/25/17
67	10/21/16	67	9/18/17	77	10/08/17	52	10/26/17
57	10/22/16	66	9/19/17	79	10/09/17	54	10/27/17
54	10/23/16	62	9/20/17	80	10/10/17	60	10/28/17
62	10/24/16	65	9/21/17	77	10/11/17	61	10/29/17
57	10/25/16	63	9/22/17	75	10/12/17	47	10/30/17
-	10/26/16	74	9/23/17	70	10/13/17	53	10/31/17
-	10/27/16	73	9/24/17	69	10/14/17	59	11/01/17
-	10/28/16	73	9/25/17	73	10/15/17	67	11/02/17
-	10/29/16	75	9/26/17	63	10/16/17	65	11/03/17
-	10/30/16	78	9/27/17	54	10/17/17	63	11/04/17

Table 3. "Facility V, X and Z", average temperatures recorded for the first two weeks after harvest at the Horticultural Crops Research Station, Clinton, NC. 2016 and 2017

2016		2017					
AVG. TEMP	H1	AVG. TEMP	H1	AVG. TEMP	H2	AVG. TEMP	H3
69	10/17/16	78	9/14/17	68	10/4/17	66	10/22/17
72	10/18/16	78	09/15/17	71	10/05/17	69	10/23/17
76	10/19/16	75	9/16/17	71	10/6/17	68	10/24/17
73	10/20/16	76	9/17/17	74	10/7/17	56	10/25/17
69	10/21/16	74	9/18/17	78	10/8/17	51	10/26/17
55	10/22/16	74	9/19/17	79	10/9/17	54	10/27/17
55	10/23/16	75	9/20/17	82	10/10/17	61	10/28/17
65	10/24/16	78	9/21/17	79	10/11/17	57	10/29/17
55	10/25/16	75	9/22/17	77	10/12/17	49	10/30/17
55	10/26/16	73	9/23/17	72	10/13/17	57	10/31/17
63	10/27/16	77	9/24/17	68	10/14/17	60	11/01/17
65	10/28/16	79	9/25/17	74	10/15/17	68	11/02/17
64	10/29/16	79	9/26/17	64	10/16/17	67	11/03/17
71	10/30/16	71	9/27/17	54	10/17/17	65	11/04/17

Table 4. “Facility U”, average temperatures recorded for the first two weeks after harvest at the Harnett County Airport, NC. 2016

AVG. TEMP	H1
69	10/17/16
73	10/18/16
75	10/19/16
74	10/20/16
67	10/21/16
54	10/22/16
55	10/23/16
63	10/24/16
56	10/25/16
55	10/26/16
62	10/27/16
65	10/28/16
64	10/29/16
70	10/30/16

Table 5. Average incidence of IN after four 30-root samples from each grower at each facility.

Harvest 1						
	Grower					
	U	V	W	X	Y	Z
Facility	Percent Incidence	Percent Incidence	Percent Incidence	Percent Incidence	Percent Incidence	Percent Incidence
U	2	6	0	2	0	3
V	0	15	1	1	1	1
W	2	6	2	6	0	4
X	19	53	23	18	13	26
Y	2	6	1	0	3	0
Z	3	6	0	1	0	0
Harvest 2						
	U	V	W	X	Y	Z
Facility	Percent Incidence	Percent Incidence	Percent Incidence	Percent Incidence	Percent Incidence	Percent Incidence
U	5	3	28	1	3	43
V	2	2	8	2	2	3
W	2	5	1	1	3	6
X	3	4	20	6	4	20
Y	3	2	28	3	10	23
Z	3	3	20	2	0	26
Harvest 3						
	U	V	W	X	Y	Z
Facility	Percent Incidence	Percent Incidence	Percent Incidence	Percent Incidence	Percent Incidence	Percent Incidence
U	0	1	2	0	1	0
V	3	1	0	3	0	1
W	0	0	2	7	0	3
X	5	3	3	0	1	1
Y	24	17	7	8	1	27
Z	4	2	3	1	1	3