ABSTRACT

GARZON, JOSE GUALBERTO. Physical and Chemical Changes to Different Varieties of Sweetpotato Subjected to Long-term Storage at Varying Environmental Conditions. (Under the direction of Michael Boyette, PhD., PE).

Over the last decade the production of sweetpotato in the US has increased by nearly 454 million kg (one billion pounds), reaching a total production of 910 million kg (two billion pounds) with a value of 424 million dollars (US Sweetpotato Collaborators Newsletter, winter 2010). North Carolina is the largest producer of sweetpotatoes in the US with an annual production of nearly 494 million kg. (NCDACS, 2010) Advances in sweetpotato long term storage have been a crucial component in making this growth possible. Under optimum storage conditions, sweetpotatoes may be held in marketable condition for longer than 10 months. This allows for orderly marketing throughout the year. In the last 20 years, several hundred long-term storage facilities have been built employing a novel air movement system now termed negative horizontal ventilation (NHV).

The goal of this research was to measure the variation in weight and respiration rate of different sweetpotato varieties under different environmental conditions and develop tools to reduce weight loss during storage periods when those conditions vary. It was also the intention to develop a respiration rate index based on dry weight loss under five different ranges of storage temperature, 14.4 - 16.6°C, 16.7 - 18.8°C, 18.9 - 21.1°C, 21.2 - 23.3°C, 23.4 - 25.6°C, at laboratory scale, and also under the

recommended conditions of 14.5 ±1˚C (58 ±2˚F) storage temperature and 85% ±5% relative humidity, in a commercial scale facilities.

Sweetpotatoes are alive and respire during storage and the rate of respiration, and consequently the weight loss, is proportional to the storage temperature. Since sweetpotatoes are sold by weight, it is beneficial to the grower to minimize weight loss while still preserving a quality product. During the 2009-2010 and 2010-2011 storage seasons, tests were conducted in one of NC State University's controlled environment rooms, where five different varieties of sweetpotatoes were placed on electronic scales and the temperature inside the rooms was changed in cycles from 14.5 to 23.3 °C (58 to 74 ˚F). The sample weights were recorded every hour over a period of 300 days. Simultaneously other electronic scales where placed in commercial facilities where the temperature was stable during the same period of the test. The data shows the daily weight loss and respiration rates under both storage circumstances (varying and constant - on and off campus) and the differences between varieties. The results yield some very interesting observations about the influence of genotypes and environmental conditions during long term storage of sweetpotatoes.

Physical and Chemical Changes to Different Varieties of Sweetpotatoes
Subjected to Long-term at Varying Environmental Conditions

by
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DEDICATION

To

My wife Iveth

And

My daughter Fiorella Sophia

BIOGRAPHY

Jose Gualberto Garzon Banderas was born on June 29^{th}, 1978 in Quito, Ecuador. His High School studies were done at the Cardinal Spellman School in Quito. After finishing High School he moved to Chile, where he conducted his undergraduate studies. In 2000, Mr. Garzon completed his studies as summa cum laude from the Escuela de Administracion Agricola at Paine, Chile. After finishing his studies, he moved back to Ecuador. In his native country he worked for a frozen food company and for companies in the fresh cut flower industries, holding the following positions: R&D Coordinator, Crop Manager, Technical Manger, and Farm Manager. In 2006, Mr. Garzon moved to the U.S. where he worked as a Project Coordinator for the AmeriCorps. This one year commitment took place in Sampson County in N.C. The goal of the project was to build a farm worker vegetable garden, and teaching farm workers how to grow a sustainable vegetable garden. In 2008, Mr. Garzon started working for NCSU as a Research Specialist in the area of vegetable production in the Department of Horticultural Science. In 2009, he started his graduate studies in the Department of Biological and Agricultural Engineering at NCSU under the direction of Dr Michael Boyette.

Jose Garzon is married to Iveth Medina, they have been blessed with a daughter, Fiorella Sophia, who is 4 months old.

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LIST OF ABREVIATIONS

V	Volts
V_{out}	Voltage output
Wt	Weight
V_R	Reference voltage
n	Number of bits in the word
ΔV_{out}	Smallest output change
NHV	Negative Horizontal Ventilation
RH	Relative Humidity
CRB	Complete Randomized Block
CA	Control Atmosphere
MA	Modified Atmosphere
R_{rt}	Respiration Rate
R_{ht}	Respiration Heat
MSE	Mean Square Error
HSD	Tukey's Studentized Range
ANOVA	Analysis of Variance
GLM	General Linear Model

Chapter 1

Introduction

Since the beginning of agriculture, farmers have faced enormous challenges. The solutions to those challenges have shaped society and in many ways initiated the development of technology and human endeavors that later evolved into many more complex civilizations. In more recent history, modern agriculture, with the help of a very diverse array of other sciences such as chemistry, entomology, genetics and engineering, have reached production levels like never before. One important result has been the generation, for the first time in human history, of a consistent production surplus in many parts of the world. Handling this surplus is especially critical in production areas located in the temperate zones of the world, where agricultural production is seasonal. The excess in production will be wasted if it cannot be either processed or stored in order to fulfill the food needs of the population throughout the year. Currently, under globalized markets, a failure in the handling of the production in a crop creates an opportunity for other countries located in less seasonal areas of the world to engage in the crop and results in migration of the agricultural production to those areas. In addition, the market's demand from growers and packers of a steady supply and superior quality throughout the year has added an extra motivation to service this market. For all these reasons postharvest technologies have evolved in order to overcome the challenges of seasonal availability. Sweetpotato (*Ipomoea batatas* (L) Lam) is an agricultural commodity which has experienced all the demands described above, starting as a crop from tropical and subtropical zones in Latin America to become the seventh most produced food commodity in the world (Kays, 2004).

Fuglie (2007) explored the most necessary priority topics that needed improvement for sweetpotatoes in developing countries. Out of 6 critical points, four are directly related to variety development and improvement; with one related to postharvest handling and marketing. These conclusions are evidence of the importance of genotype in crops, and how it is expressed in different environments and under stress conditions. The other point is storage, the subject of this research, which is directly responsible for successful marketing even in areas where the harvest season is not restricted to a few months a year.

1.1 Background

In the United States, the production of sweetpotatoes has grown in number and importance in the last decade, increasing from 1 billion pounds production in 2001, to 2 billion pounds in 2011 with a value of 424 million dollars. (The United States Sweetpotato Council Inc. National Sweetpotato Newsletter, 2012). In order for sweetpotatoes to experience this growth and to adapt to the demands and characteristics of the market, it has been necessary to overcome several difficulties. Certainly the most important and influential aspect which has allowed sweetpotato production to grow is proper long term storage. In order to market a consumer perishable agricultural commodity, it has to be stored. This storage can be several hours, days, weeks, or months as it is the case of sweetpotato roots stored under their ideal conditions of 14.4˚C and 85% relative humidity (Kushman and Pope, 1972). Flanders et al (1998) emphasizes the importance of storage by stressing in their publication that *"All the expense and effort of making a crop can be wasted if no attention is paid to storage"*

Successful sweetpotato storage is the result of applying several different measures correctly, which includes the right cultural, sanitary, and pest management practices. However, the two factors that affect storage the most are the genotype of the stored sweetpotatoes and the temperature at which they are stored. Genotype has been the most important factor in other studies (Buescher, 1977 and Hall 1985), where even though they were looking for variables other than storage, sweetpotato variety was the most significant variable. When sweetpotato growers and packers have reported a reduction in weight and volume of sweetpotatoes after long term storage periods, this reduction is commonly known as "shrinkage". Hence, this study investigated the effects of different temperature levels on five sweetpotato varieties during 10 months of storage.

North Carolina is currently the largest producer of sweetpotatoes in the US. (NCDACS, 2010). The state produced 494 million kg in 2010, 6% increase in relation to 2009 (NCDACS, 2010). The growth in sweetpotato production is largely possible as a result of the improvements in long term storage conditions as growers provide for expanding consumption, processing and export markets. Production in 1950 was 169 million kg, in 2009 it had grown to 467 million kg (NCDACS, 2010), which reflects a total increase of 276%, or approximately 5% increase annually.

Storage conditions have evolved in the last 50 years from barns with little, if any cooling, heating or ventilation systems, to natural convection storage rooms, where growers and packers started to control the temperature and relative humidity. These early facilities allowed the handling of sweetpotatoes in 450 kg pallets bins with the help of forklift trucks, but their size were limited to no more than about 10,000 kg (22,000 lbs) of roots, The fundamentals of this system were developed by Kushman and Wright (1968), and consisted of trenches built into the concrete floor that were spaced about 3m apart and were 30 cm wide by 30 cm deep. (Boyette, 2009), These trenches were covered with 5 cm thick boards of oak spaced about 2 cm apart. These trenches were filled about 5 cm deep with water and acted as distribution ducts for warm air from an fuel-oil furnace. The air from the trenches moved by natural convection up through the pallet bins of sweetpotatoes stacked 4 to 5 meters high. (Boyette, 2009).

In the late 1980s, a new type of sweetpotato storage system was developed that relies on forced convection to distribute the air horizontally throughout the room utilizing the fork lift slots as mini-ducts. Nearly all the approximately 436 million kg (16 million bushels) of sweetpotato storage currently used in North Carolina employ this design. This system is called negative horizontal ventilation (NHV), and makes it possible to maintain specific temperature and relative humidity conditions with the use of electronic controls and sensors under normal operating conditions, the difference between any two points in the room with respect to temperature and relative humidity should differ no more than ±1˚C, and ±3% respectively. Some of the larger of these rooms may be more than 50 m by 40 m with 8 m height and hold over 1.6 million kg (60 thousand bushels) of sweetpotatoes.

1.2 The Curing and Storage Process

Immediately after harvest, sweetpotatoes are cured by a process where sweetpotatoes are held at 30˚C and 85% relative humidity for 5 to 8 days depending on the harvest conditions, intended use and other factors. The beneficial effects of curing have been recognized for over two centuries. One of the main effects of curing is to provide conditions for healing in areas where the skin is wounded by cuts and bruises caused during harvesting and handling. The wounded area is transformed into corky tissue by infiltration with suberin; healing the wounded surface by the process called suberization (Blankenship and Boyette, 2002). Other desired effects of curing are reduction of water loss and decay during storage. An additional and very important effect is that starches are converted into sugars which enhances the taste (Kader et al., 2002).

Sweetpotatoes are susceptible to chilling injury when stored under 10˚C (Boyette, 2009). The level of injury is a function of both the temperature and time. For example, 10 hours at 5˚C may result in the same level of injury as 50 hours at 7˚C. Chilling injury is considered a postharvest disorder most often resulting from mismanagement of storage temperature. Another postharvest disorder related to temperature mismanagement is called hardcore. Both disorders render the sweetpotatoes unsalable, causing large loses. This disorder is particularly insidious since it often only show their symptoms much later when the product reaches the final consumer. Hardcore especially appears after cooking as unsoftened tissue, which results in the consumers becoming averted from sweetpotatoes and thus negatively affecting consumption. (Buescher, 1977). The incidence and severity of disorders like hardcore are affected by genotype (Broadus et al, 1979), which proves the behavior of different sweetpotato varieties can be very different.

Until now, there has been a lack of studies on how the different genotypes react at different temperatures during long term storage. Sweetpotatoes are alive and respire during storage and the rate of respiration, and consequently the weight loss, is proportional to the storage temperature. Since sweetpotatoes are sold by weight, it is beneficial to the grower to minimize weight loss while still preserving a quality product. If the temperature is held at temperatures above16˚C for periods longer than a few days, the result is sprouting, pithiness, poor appearance and the increased incidence of postharvest rots (Boyette, 2009). Current storage recommendations for all commercial US varieties of sweetpotatoes are a temperature of approximately 14˚C and 85% to 90% relative humidity (Kushman, 1975). A very limited number of studies in sweetpotato storage under control atmosphere (CA) techniques have been conducted with generally disappointing results.

Improper handling and decay can cause a loss of up to 50% of weight after 10 months of storage (Kushman, 1975), (Chang and Kays, 1981). Studies in CA storage helped to establish limits in oxygen concentrations during storage to avoid product damage. Sweetpotatoes stored at oxygen levels below 2.5% develop fermentation symptoms; at 5 to 15% oxygen concentration the respiration rate was lower than when roots were stored at 2.5% or 20% (ambient) oxygen concentrations (Chang and Kays, 1981). Since weight losses under 10% after 10 months of storage can be achieved without CA, the use of CA technology has been shown to be uneconomical.

The present study attempts to develop tools and understandings that will help optimize the technology that is currently in place. Other changes in sweetpotato during storage have been reported such as changes in dry matter, protein and non-protein nitrogen. The percentages of these components will decrease as the storage period increases. In general, the loss of dry matter is twice as fast as the loss in protein, but it varies between varieties and for some varieties those changes are not significant (Purcell et al., 1978)

1.3 Preharvest Conditions

Preharvest conditions and treatments also affect the storage yields of sweetpotato. Even though factors like fertilization, soil characteristics and presence of weeds can play an important role, temperature and humidity are the two factors that can affect the sweetpotato weight loss most during long term storage. Ahn, Collins, and Phar, (1980) studied the interaction of high humidity and dry conditions, with cold and warm temperatures, and its impact during storage in two sweetpotato varieties. Additionally, the authors investigated flooded (saturated) soil conditions with both hot temperatures (24 to 34˚C), and cold (4˚C). Warm-flooded conditions resulted in a greater presence of decay-causing organisms. On the other hand, cold-flooded conditions did not show rotting symptoms during curing, but decay advanced quickly in storage. Cold-dry treated roots show no decay at the beginning but after 52 days in storage decayed root increased rapidly. Not surprisingly, warm-dry pre-harvest conditions yielded better results in long term storage and levels of respiration were lower than those in the other three treatments. Between warm-flooded, cold-flooded, and cold-dry treatments there were no significant differences in respiration rates, however, the differences between varieties were significant (Ahn et al., 1980). Conclusions from this study show the importance of preharvest factors and variety selection.

Nitrogen fertilization can affect long term storage results as well, consequently fertilization levels during pre-harvest growth have shown to be of importance. Further, nitrogen amendments shortly before harvest will set the level of protein nitrogen of mitochondria in root tissues at harvest, which stays constant at storage (Minamikawa et al., 1961). Nitrogen fertilization recommendations vary greatly between from 0 to 146 kg N/ha. Numerous studies conducted in order to determine the most appropriate rate of nitrogen fertilization are not in agreement because other factors like soil texture and fertility, weather, previous crops and timing are different at each location, However, at the highest rates of nitrogen applications, roots will yield the highest tissue N concentration. Also, the high levels of N will yield the lowest total sugars and starch content in tops but bigger root size at harvest and also the greatest number of roots per plant. Finally, dry matter percentage and carotene content will increase linearly with N fertilizations at the rate of 0 to 67 kg N/ha; but at 101 to 202 kg N/ha, dry matter percentage will decrease (Villagarcia, 1996)

The present sweetpotato storage experiment was conducted during the 2009-2010 and 2010-2011 storage seasons in one of the North Carolina State University controlled environment cooler rooms, where five different varieties of sweetpotatoes were placed on electronic scales and the temperature inside the cooler was changed in cycles from 14.5 to 23.4˚C. The weight of each sample was recorded every hour over a period of 300 days. Simultaneously five other electronic scales where placed in commercial storage facilities equipped with negative horizontal ventilation systems, where the temperature was stable at 14.5˚C during the same 300 day test period. This study shows the daily weight loss under both circumstances; the difference between varieties and further yields some interesting observations about the influence of genotypes and environmental conditions during long term storage of sweetpotatoes.

Chapter 2

Instrumentation

2.1 Introduction

A thorough description of the instruments used in this study is important because measuring the physical change in weight of the sweetpotatoes is the result of measuring a different but related variable and establishing the relationship between it and weigh. The original variable is measured by physical sensors which are load cells. The voltage out of the load cells is collected in data loggers from which it is extracted into the computer where it is transformed to weight values by using a conversion equation. This equation establishes the relationship between the original measured parameter and the desired weight value. This set of equipment and software constitutes the basic components of the data acquisition system employed in this study.

2.2 Sensors

Bending beam load cells are strain sensors used for the measurement of weight. Weight is the force resulting from the multiplication of the body mass by the gravitational constant. Load cells are an assembly of a beam or a yoke that has several strain gauges positioned in a manner that the application of a force causes a strain in the system measured by the gauges. (Johnson, 2006). A working definition of strain, according to Johnson, 2006 is: "The resulting deformation of a solid, which is the effect of an applied force referred to as a stress" The gauges are composed of a material that changes its electrical resistance due to the applied force (strain). Therefore, by measuring the change of resistance due to the applied load, value of the applied force (weight) may be determined. The load cell sensors used for this study along with the necessary equations are described in the following sections.

2.2.1 Small Load Cells (30 kg max. load)

These sensors were used to collect the weight change of sweetpotatoes located in the on-campus controlled environment rooms, where the reaction to temperature change experiment took place. The load cells were bending beam load cells, TEDEA RL1042 made of anodized aluminum, 2 mV/V output sensitivity, 0.02% nonlinearity or total error, maximum load capacity 30 kg. The voltage output (V_{out}) generated from the load cells was logged in data loggers - HOBO, model U12-006 (Onset Computer) with 4 external data channels. Therefore for the 20 load cells needed in this experiment, 5 data loggers were required. The bending load cells are shown in figure 2.1. And the hardware of the data acquisition system is shown in figure 2.2

Figure 2.1: TEDEA bending beam load cell RL1042, max capacity 30kg

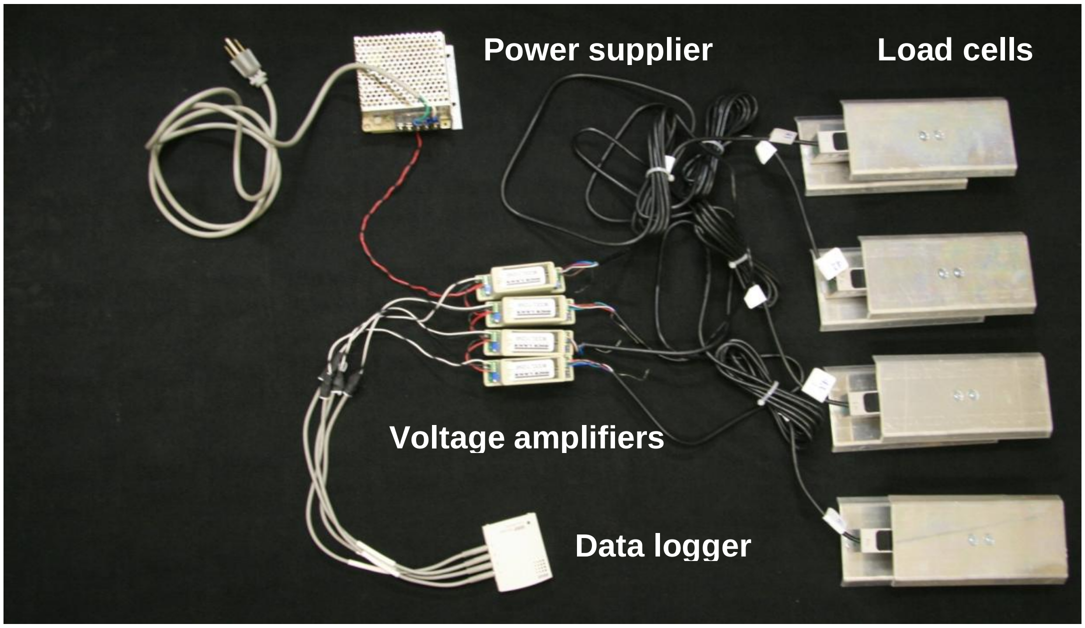

Figure 2.2: Complete hardware data acquisition system utilized in the NCSU controlled environment campus coolers

2.2.1.1 Resolution

Knowing the minimum measurable change is a very important factor in designing a data acquisition system. In this study resolution would be the minimum amount of change in weight that we can determined and the conversion resolution the smallest voltage out (ΔV_{out}) that can be measured. A more formal definition of conversion resolution is given by Johnson, 2006: “The conversion resolution is a function of the reference voltage (V_R) and the number of bits in the word (n)”. Therefore, a system will be more accurate when there are more bits, because it would be able to measure a smaller change in analog output (Johnson, 2006). It is given by:

$$\Delta V_{out} = V_R 2^{-n} \tag{2.1}$$

$$V_R = 2.5\ V$$

$$n = 12$$

$$\Delta V_{out} = (2.5)2^{-12}$$

$$\Delta V_{out} = 0.00061\ V$$

Since the maximum possible weight of 30 kg will give a V_{out} = 2.5 V, 0.00061 V gives a weight resolution of 7.32 g.

2.2.1.2 Calculations

The necessary calculations to convert V_{out} to weight (Wt) are explained in detailed below.

The first step is to calculate the V_{out} per unit of weight. The calculation was done by dividing the voltage difference by the weight difference. For the 2010 experiment,

V_{out}/Wt was calculated by measuring the difference between V_{out} at 13.6 kg (30 lb) and at 25 kg (11.36 lb), and the value then was divided by the resulting value of the subtraction of 13.6 kg from 25 kg, which is 11.4 kg (25 lb). Thus we obtain the following equation:

$$\frac{V}{Wt} = \frac{(V_{out@25} - V_{out@13.6})}{(25 - 13.6)kg} \tag{2.2}$$

In order to increase accuracy and to take into account rotten roots, for the 2011 experiment V_{out}/Wt was calculated by measuring the difference between V_{out} initial and final. Then it was divided by the difference between final and initial weight. The percentage weight of the rotten roots was subtracted from both initial and final weights. it is important to note that for the 2010 experiment, there were no decayed roots. Thus we obtain the following equation:

$$\frac{V}{Wt} = \frac{\left(V_{outfinal} - V_{outinitial}\right)}{\left(Wt_{final} - Wt_{initial}\right)kg} \tag{2.3}$$

These calculations were made for each individual load cell sensor, obtaining the values shown in table 2.1:

Table 2.1: Individual Load Cell V_{out}/Wt

	2010	**2011**
Load Cell #	**V/kg**	**V/kg**
1	0.13703	0.13766
2	0.12283	0.08083
3	0.13650	0.22467
4	0.13768	0.13282
5	0.13693	0.16521
6	0.13693	0.00862
7	0.13671	*
8	0.13526	0.12848
9	0.13660	0.15710
10	0.15948	0.16982
11	0.13537	0.18871
12	0.13730	*
13	0.13838	*
14	0.13725	*
15	0.13854	0.06404
16	0.13677	0.16934
17	0.13677	0.19324
18	0.13547	0.14976
19	0.13542	0.16603
20	0.13526	0.17286

* Impossible to calculate due to equipment malfunction

The second step was to establish a theoretical V_{out} , which was calculated with the following equation:

$$theoretial\, V_{out} = Wt_{initial} \times \frac{V}{Wt} \tag{2.4}$$

The theoretical V_{out} will be used in a relationship in order to calculate the deviation of the actual V_{out}. This relation will be the bias which will take into account the error caused by the signal conditioning at different weights.

$$bias = actualV_{out} - \ theoreticalV_{out} \tag{2.5}$$

In order to convert the output, which is V_{out}, in the desired parameter (weight), the logical approach to this problem is to develop an equation for the output in terms of the input (Johnson, 2006)

$$V_{out} = Wt_{actual} \times \frac{V}{Wt} + bias \tag{2.6}$$

Therefore,

$$Wt_{actual} = \frac{V_{out} - \ bias}{\frac{V}{Wt}} \tag{2.7}$$

2.2.1.3 Temperature Correction

Even though this load cells are temperature compensated from -10 to 40 ˚C, as shown in the specification sheet in Appendix A, after the first set of measurements some fluctuations due to change in temperature were evident, so in order to eliminate noise from the output, an further experiment was conducted. Known weights were placed on the load cells and then the temperature was fluctuated the same ranges and periods at which the sweetpotatoes were exposed in the original experiment. The results were the compensation factors for each load cell due to the changes in temperature (Table 2.2).

Table 2.2: Load Cells Correction Factors For Different Temperature Ranges

Load Cell #	12.8 to 15.6 ˚C	15.6 to 18.3 ˚C	18.4 to 21.1 ˚C	21.2to 23.9˚C
1	0.00229	0.00628	0.00996	0.01328
2	0.00156	0.00446	0.00667	0.00935
3	0.00262	0.00262	0.00965	0.01324
4	0.00133	0.00483	0.00820	0.01224
5	0.00179	0.00512	0.00797	0.01232
6	-0.00221	-0.00823	-0.01458	-0.02255
7	0.00099	0.00420	0.00774	0.01132
8	0.00102	0.00452	0.00818	0.01215
9	-0.00008	0.00225	0.00457	0.00721
10	0.00078	0.00571	0.00968	0.01485
11	0.00084	0.00457	0.00805	0.01305
12	0.00000	0.00000	0.00000	0.00000
13	0.00000	0.00000	0.00000	0.00000
14	0.00038	0.00286	0.00527	0.00893
15	0.00025	0.00257	0.00532	0.00889
16	0.00031	0.00231	0.00512	0.00862
17	0.00138	0.00212	0.00153	-0.00144
18	-0.00136	-0.00997	-0.02040	-0.03473
19	-0.00024	-0.00310	-0.00738	-0.01502
20	-0.00101	-0.01273	-0.01751	-0.02908

2.2.2 Platform Load Cells

The platforms were built from steel channel and were designed to support a stack of 1090 kg (40 bushel) pallet bins. The platforms were 1.1m wide by 2.4m long. One platform is shown in figure 2.3.

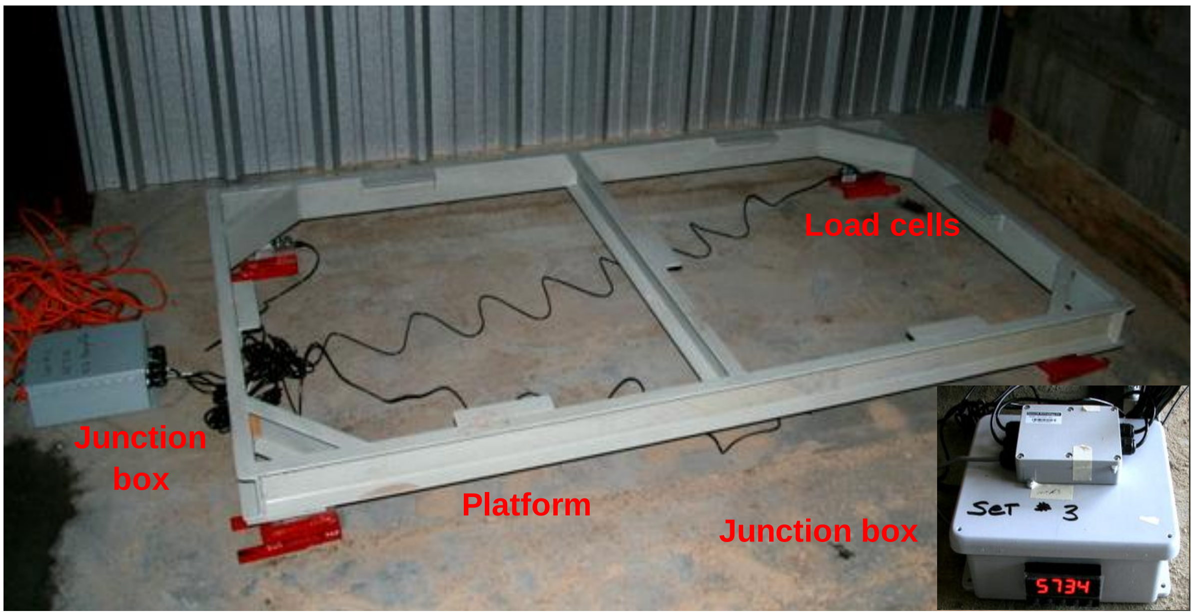

Figure 2.3: Platform load cell set.

Five platforms were built, one for each location. Each platform had 4 load cells, one at each corner and each load cell had a maximum load capacity of 2,273 kg (5,000 lb). The combined voltage of the four load cells was added in an electrical junction box, giving to the platform the total capacity of up to 9,000 kg (20,000 lb). These platforms were used to measure the weight change of sweetpotatoes located in the commercial storage coolers off-campus. The load cells were single ended shear beam load cells, RF model: SBS-5KSE, 2.99960 mV/V output sensitivity, 0.02%

nonlinearity or total error with a maximum load capacity 5,000 lb. The voltage output (V_{out}) generated from the system was logged in HOBO, model U12-013 data loggers with 2-channels of external data input. These units also support and supported measurement of temperature and relative humidity.

2.2.2.1 Resolution

Knowing the minimum measurable change is a very important factor in designing a data acquisition system. In this study resolution would be the minimum amount of change in weight that we can measured and the conversion resolution the smallest voltage out (ΔV_{out}) that we can measure. From the definition used in section 2.2.1.1 and equation 2.1, the following values were obtained:

$$V_R = 2.5\ V$$

$$n = 12$$

$$\Delta V_{out} = (2.5)2^{-12}$$

$$\Delta V_{out} = 0.00061\ V$$

Since the maximum possible weight of 9,000 kg will give a V_{out} = 2.5 V, 0.00061 V gives a weight resolution of 2.196 kg. or a change of 0.0244% of total weight.

2.2.2.2 Calculations

The original calculations for the platform scales were done in pounds (lb), so with a maximum V_{out} of 2.5 V, and following calculations of section 2.2.2.1 gives a weight resolution of 4.88 lb per each 0.00061 V; thus the relation between V_{out} and weight is given by a factor of 8,000.

$$\frac{4.88\ lb}{0.00061\ V} = 8{,}000\frac{lb}{V} \tag{2.8}$$

Equation 2.8 gives the necessary constant to calculate the weight in pounds from the voltage measured by the load cells. Therefore we can establish the following equation:

$$V_{out} \times 8{,}000\frac{lb}{V} = weight\ in\ lb \tag{2.9}$$

In order to convert the weight in pounds into kg, it is necessary to divide the resulting value from equation 2.9 by the constant 2.2 lb/kg:

$$weight\ in\ lb \div 2.2\frac{lb}{kg} = weight\ in\ kg \tag{2.10}$$

2.2.3 Temperature/Relative Humidity Sensors

Measuring temperature and relative humidity in the storage rooms, on-campus and in the commercial facilities, was done with the use of HOBO U12 temperature/relative humidity data loggers. These units each have 2-channels. These loggers are equipped with sensors which allow them to have the following specifications:

Measurement Range:

Temperature: -20° to 70°C (-4° to 158°F)

RH: 5% to 95% RH

Accuracy:

Temperature: ± 0.35°C from 0° to 50°C (± 0.63°F from 32° to 122°F)

RH: ±2.5% from 10% to 90% RH, to a maximum of ±3.5%.

Resolution:

Temperature: 0.03°C at 25°C (0.05°F at 77°F),

RH: 0.03% RH

In the on-campus controlled environment room, 2 data loggers were placed per repetition, giving a total of 8 data loggers inside the room. In the commercial storage rooms, 2 data loggers were placed per room.

The values reported are the average temperature and relative humidity at each location.

Chapter 3

Sweetpotato Weight Loss during Long Term Storage

3.1 Introduction

Sweetpotatoes are alive and respire during storage and their weight loss is proportional to the storage temperature. During 2009-2010 and 2010-2011, tests were conducted in one of the NCSU controlled environment storage room to study the effect of long-term storage on five varieties of sweetpotatoes. Sweetpotato varieties “Beauregard”, “Covington”, “Evangeline”, “Carolina Rose” and “Hatteras were placed on electronic scales. The room temperature was changed in cycles from 14.5 to 23.4˚C (58 to 74˚F) (Figure 3.1), while relative humidity (RH) remained constant at 85% ±5%. Weight was recorded every hour over a period of 300 days. Simultaneously, electronic scales where placed in commercial facilities where the temperature and RH were stable during the same period of the test at 14.5 ±1˚C (58 ±2˚F) and 85% ±5%. Hourly weight was measured as well. The data shows the daily weight loss at all locations. It also shows the difference between varieties and yields some interesting observations about the influence of genotypes and environmental conditions during long term storage of sweetpotatoes.

The objective of this study was to establish the different behavior of five commercially grown sweetpotato varieties of ‘Beauregard”, “Carolina Rose”, “Evangeline”, “Hatteras” and “Covington” during long term storage under controlled temperature cycles from 14.5 to 23.4˚C. The intent is to demonstrate that small changes in temperature can have great impact in weight loss during storage. Also it is to compare and contrast the weight loss of the sweetpotato variety “Covington” during long term storage in commercial facilities using NHV systems at a stable temperature (14.5 ±1˚C) and Covington’s behavior in the experimental conditions described above.

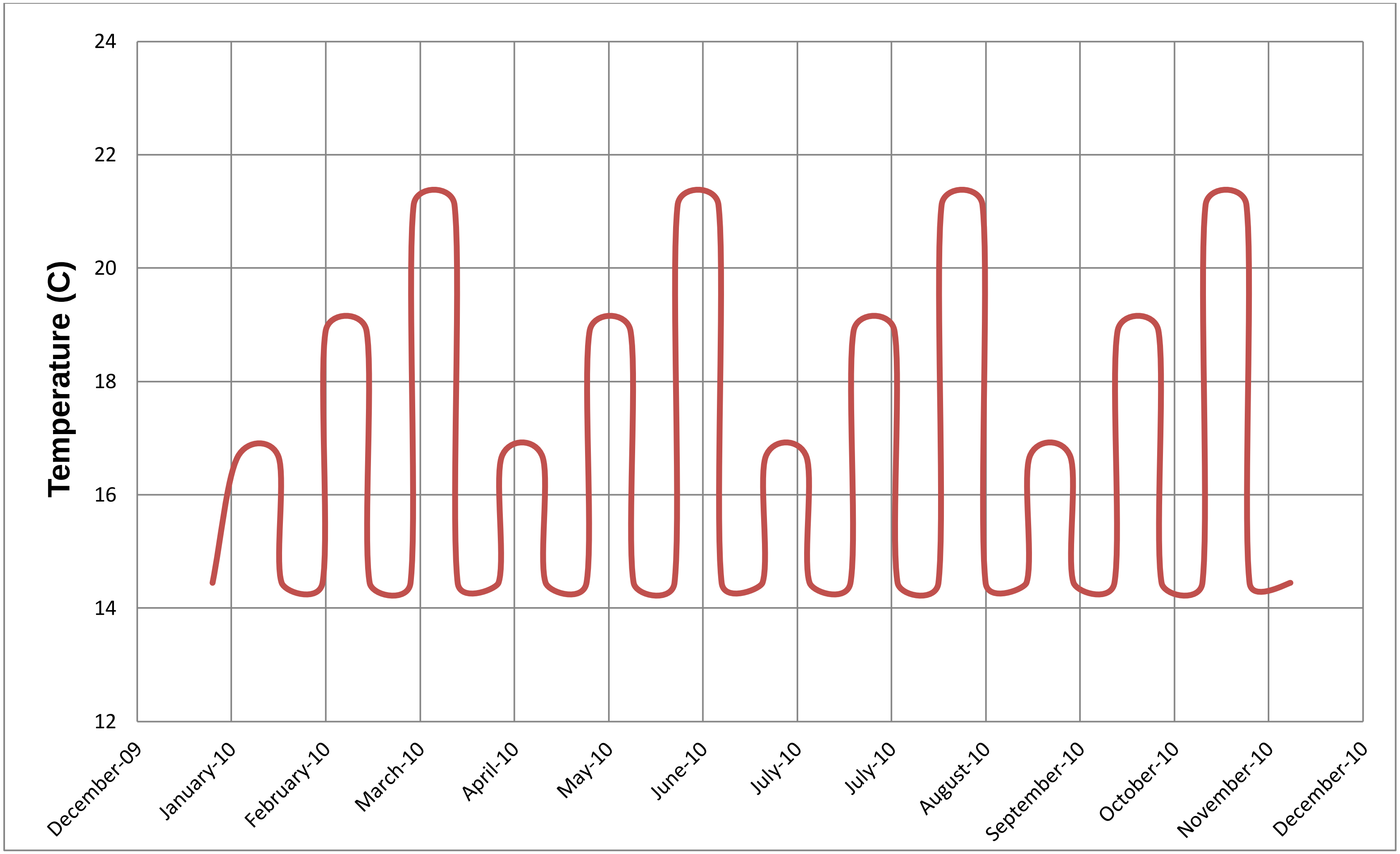

Figure 3.1: Desire temperature Cycle for Sweetpotato Long Term Storage Under Variable Temperature Conditions

3.2 Materials and Methods

3.2.1 Data Acquisition System

The Data Acquisition System that was used for this study was designed and built with the specific purpose of collecting the weight of the sweetpotatoes in two circumstances:

The first condition was a lab scale study where five sweetpotato varieties were stored separately in plastic lugs with a total gross weight of approximately 20 kg each. They were placed over bending beam load cells sensors with a maximum capacity of 30 kg. Each variety was replicated 4 times, and the experimental design was complete randomized block (CRB).

The second condition was a commercial scale experiment, where a platform with four load cell sensors capable of measuring up to 2,273 kg (5,000 lb) each, giving a total of 9,100 kg (20,000 lb). Each platform was placed in commercial storage rooms equipped with NHV systems during 2010. Five platforms with the same characteristics were built and installed for the 2011 storage term. Each platform was located in a different commercial facility All of the commercial storage rooms that participated in this study were equipped with NHV systems.

In both situations described above, weight, temperature and RH was recorded hourly by data loggers, and the data collected was analyzed utilizing specialized software. A detailed description of the data acquisition system is explained previously in Chapter 2.

3.2.2 Sweetpotato Long Term Storage

The data collected for this study was collected during two storage periods. The first period was from December 2009 to September 2010, this period is going to be referred as the 2010 storage term. The second period was from December 2010 to September 2011, this period is going to be referred as the 2011 storage term.

For the 2010 storage term, there were two different locations, one was a lab-scale study conducted in a controlled environment room on-campus, and the second location was a commercial scale site study conducted in a commercial storage room in Tull Hill Farms, located in Kinston, NC. For the lab-scale experiment the sweetpotatoes roots that were tested were from five commercial varieties: “Beauregard”, “Evangeline”, “Covington”, “Carolina Rose”, and “Hatteras”. All those varieties are of similar characteristics, they are primarily for fresh consumption, and have orange flesh and skin. They were collected from the breeders at North Carolina State University, therefore, the conditions under which they were grown, were not controlled. However they were cured in the cure-storage rooms at the Horticultural Crops Research Station in Clinton, NC. where they were kept at 29.4 °C (85 °F) and 85% RH for 7 days. After curing they were taken to the controlled environment room on-campus at NCSU in Raleigh, NC. Eighty kg of sweetpotatoes grading U.S. No. 1, according to the U.S. Standards for Grades of Sweetpotatoes, were selected and placed in plastic lugs of approximated 20 kg each, then each lug was placed on individual load cell weight sensors.

The experimental design for this study was 5 varieties, and 4 repetitions, arranged as a complete randomized block (CRB), where each repetition was place at one shelf level as represented schematically in Figure 3.2. The study had three identical temperature cycles from 14.5 to 23.4˚C (58 to 74˚F) (Figure 3.1) where each temperature point was maintained for two weeks. The temperature intervals were kept only two weeks long in order to avoid sprouting of the sweetpotatoes. (Sprouting will occur when sweetpotatoes are held for more than two weeks at the elevated curing temperature. Temperature intervals started at the recommended, then the roots were exposed to the next temperature level, then the temperature was lowered again, and so on until completing the cycle.

Beauregard	C. Rose	Hatteras	Evangeline	Covington	Rep 1
Evangeline	Hatteras	Covington	Beauregard	C. Rose	Rep 2
Hatteras	Beauregard	Evangeline	C. Rose	Covington	Rep 3
Covington	Hatteras	C. Rose	Beauregard	Evangeline	Rep 4

Figure 3.2: Varieties arrangement inside storage cooler with variable temperature.

In order to reduce variability, for the 2011 storage season, the sweetpotatoes were produced at the Lower Coastal Plain Tobacco Research Station located at Kinston, NC.. The sweetpotato roots were harvested on September 20th, 2010. The sweetpotatoes from the five varieties were hand harvested and gathered in 20 bushels bins. Each variety was clearly identified, and transported to the Horticultural Crops Research Station in Clinton, NC, were they were cured at 29.4 °C (85 °F) and 85% RH for 7 days. After curing they were transported to the NCSU campus controlled environment room number 28, located in Kilgore Hall. The roots then were placed under the same conditions as during the 2010 storage season and over the same bending beam load cell sensors. The same randomization and temperature cycles described in figures 3.1 and 3.2 were also utilized.

For the 2010 storage season there was only one commercial grower who participated in the study. Tull Hill Farms located in Kinston, NC. The sweetpotatoes used for the study were harvested on October, 2009. The data for the study was recorded beginning on December 16th, 2009 and concluded on July 29th, 2010. The variety used was “Covington”, and the experiment was conducted in storage room 2 at the Hill facility. The temperature and RH were kept stable and were recorded during the test period. The results of the recordings are represented in figure 3.7. Tull Hill farms also repeated the study for the 2011 Storage season. During that season, the sweetpotatoes were harvested in October, 2010. The data for the study was recorded beginning on October 30th, 2010 and concluded on July 28th, 2011.

The variety used was "Covington", and the 2011 experiment was conducted in Hill's storage room number 2 as well. The temperature and RH were kept stable and they were recorded during the same dates. The results of the recordings are represented in figure 3.8.

During the 2011 storage season, five commercial growers located in eastern North Carolina collaborated with the study. One of the five was Tull Hill Farms of Kinston, whose conditions are described in the paragraph above. The second commercial storage room that took part of the study was located at J.B. Rose and Sons Farms in Spring Hope, NC. The sweetpotatoes used for the study were harvested on October 15th, 2010. The data recording began on January 7th, 2011 and concluded on July 28th, 2011. The variety used was Covington, and the experiment was also conducted in Rose's storage room two. Temperature and RH were kept stable and they were recorded during the same dates. The results of the recordings are represented in figure 3.9.

Barnes Farms, located in Spring Hope, NC, is another collaborator for this project. The sweetpotatoes used for the study were harvested there on October 20th, 2010. The data for the study started to be recorded on December 10th, 2010 and was collected until July 5th, 2011. The variety used was "Covington", and the experiment was conducted in storage room 16. Temperature and RH were kept stable and they were recorded during the same dates. The results of the recordings are represented in figure 3.10.

Warren Farms, located in Clinton, NC, also collaborated with this study. The sweetpotatoes used for the study were harvested on October 21st, 2010. The data for the study started to be recorded on January 7th, 2011 and concluded on July 28th, 2011. The variety used was “Covington”, and the experiment was conducted in Warren’s storage room four. Temperature and RH were kept stable and they were recorded during the same dates. The results of the recordings are represented in figure 3.11.

Vick Farms, located in Wilson, NC, was the fifth commercial sweetpotato grower that participated in this study. The sweetpotatoes used for the study were harvested on October 27th, 2010. The data for the study started to be recorded on January 9th, 2011 and concluded on August 31st, 2011. The variety used was “Covington”, and the experiment was conducted in Vick’s storage room two. Temperature and RH were kept stable and they were recorded during the same dates, the results of the recordings are represented in figure 3.12.

3.3 Results

3.3.1 Variable Temperature Laboratory Scale Study.

Figures 3.3, and 3.4, represent the data collected during the 2010 and 2011 storage season, along with the temperature cycle subjected to the five sweetpotato varieties during the experiment. Figures 3.5 and 3.6 represent the results obtained from the five sweetpotato varieties during the 2010 and 2011 Storage seasons.

The following Table 3.1 summarizes the results obtained during the two storage seasons, comparing the percentage of weight loss of the sweetpotato varieties against the control variety “Beauregard” which is the variety that had the best results after the two storage seasons

Table 3.1: Difference in Weight Loss of the Sweetpotato Varieties compared to Beauregard for the 2010 and 2011 Storage seasons at variable temperature storage

	2010	2011
BEAUREGARD	0%	0%
COVINGTON	0%	1.4%
EVANGELINE	1.8%	3.6%
HATTERAS	3.6%	3.8%
CAROLINA ROSE	7.7%	4.3%

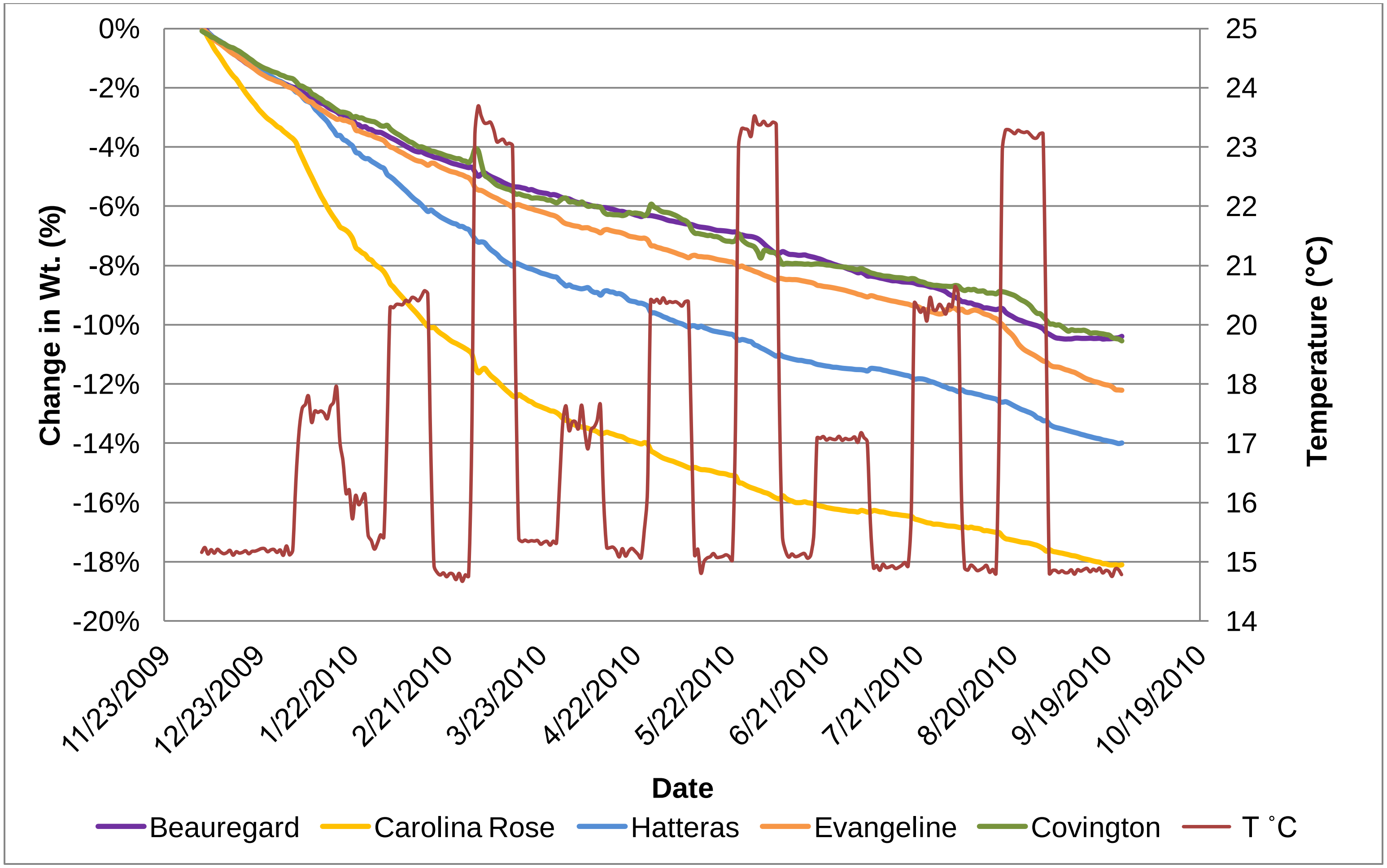

Figure 3.3: Percentage Change in Weight vs. Temperature, of Five Sweetpotato Varieties. Data derived from measurements taken during the 2010 Storage Season.

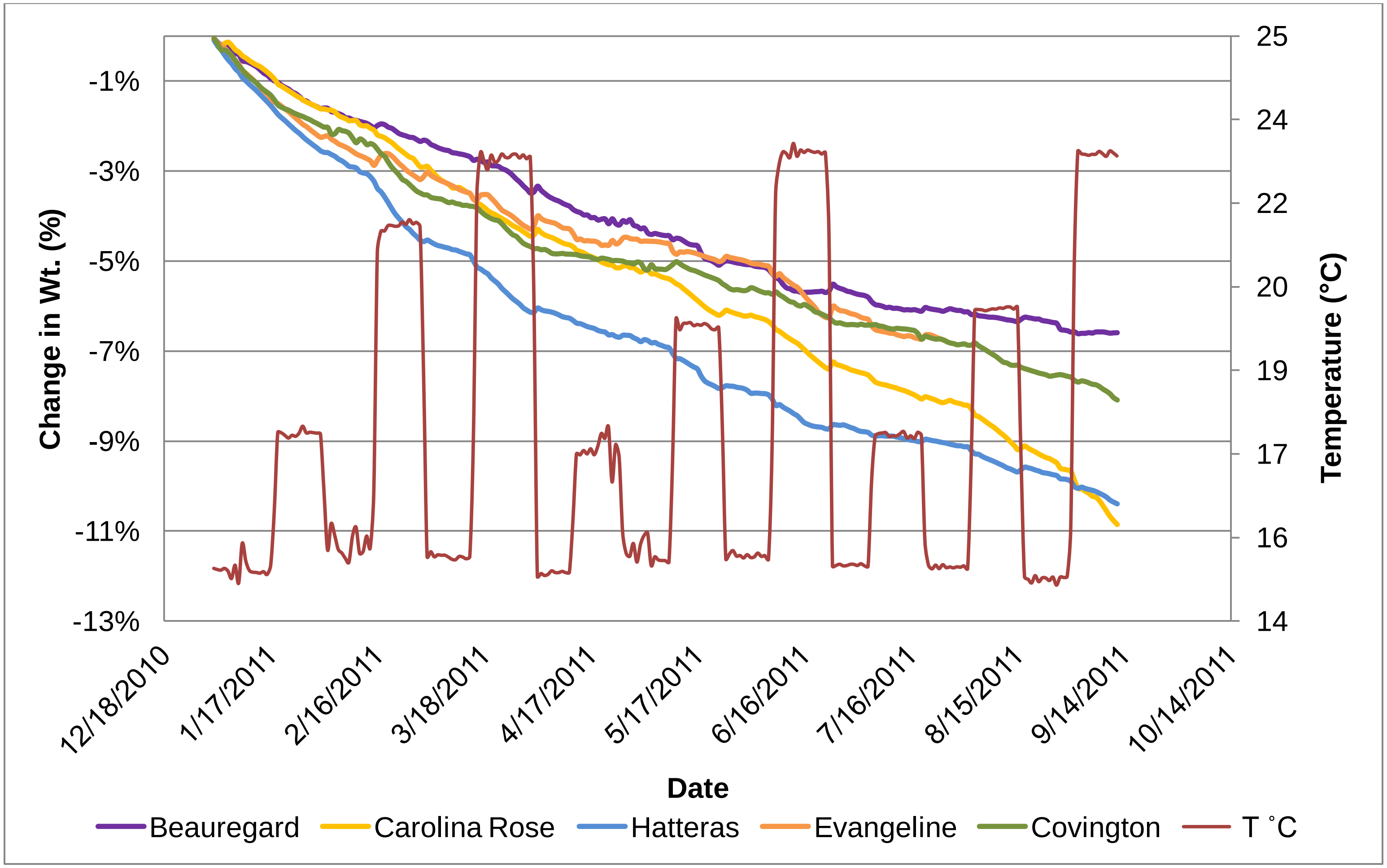

Figure 3.4: Percentage Change in Weight vs. Temperature, of Five Sweetpotato Varieties. Data derived from measurements taken during the 2011 Storage Season.

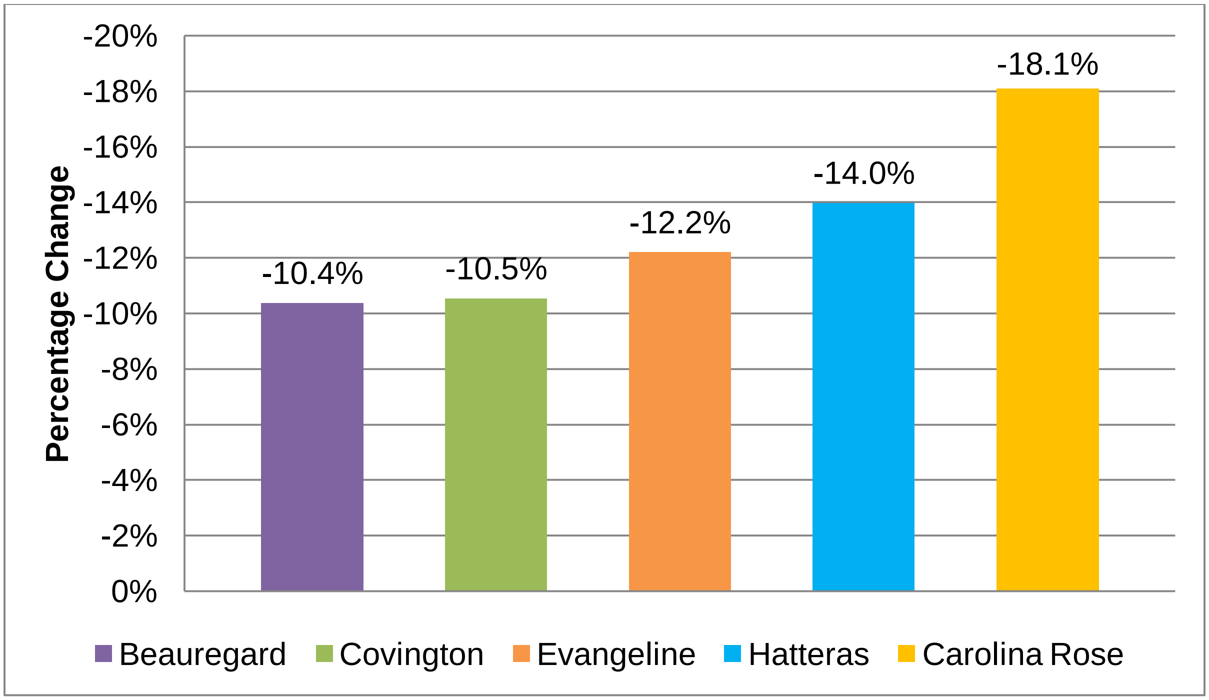

Figure 3.5: 2010 Storage season Results for Sweetpotato Long Term Storage under Variable Temperature Conditions

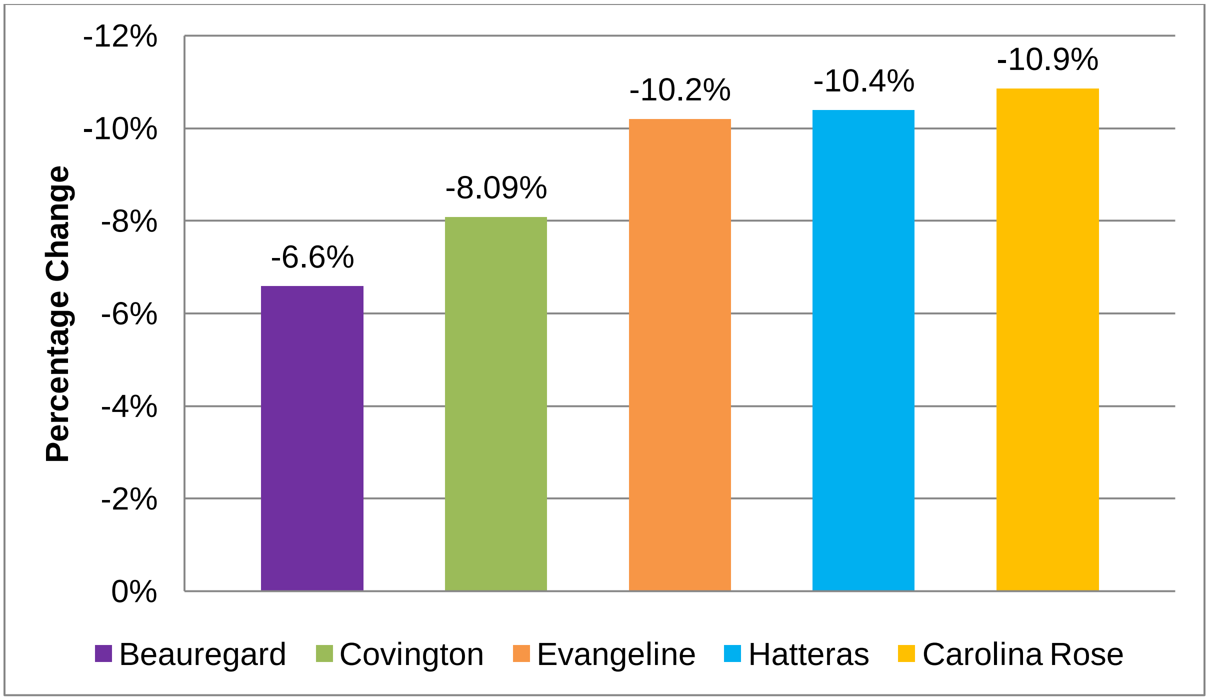

Figure 3.6: 2011 Storage season Results for Sweetpotato Long Term Storage under Variable Temperature Conditions

3.3.2 Commercial Facilities

The commercial sweetpotato facilities that participated in this study are all located in eastern NC, and all of them are equipped with NHV systems. The storage temperature was held at the standard industry recommendations. Tull Hill Farms is the only grower that participated during both storage seasons. The other four growers participated during the 2011 storage season only. Figures 3.7 to 3.12 represent the data that we collected during the study, which has been summarized in the following table:

Table 3.2: Commercial Scale weight loss Control under Stable Temperature conditions (variety "Covington")

GROWER	% CHANGE	MONTHS STORED	% AVERAGE PER MONTH
Tull Hill 2010	-6.02	8	-0.75%
Tull Hill 2011	-7.73%	10	-0.77%
Rose Farms	-4.21%	8	-0.53%
Barnes Farms	-6.53%	9	-0.73%
Warren Farms	-3.92%	8	-0.50%
Vick Farms	-5.35%	8	-0.69%

Figure 3.7: Tull Hill Farms 2010 Storage season Results

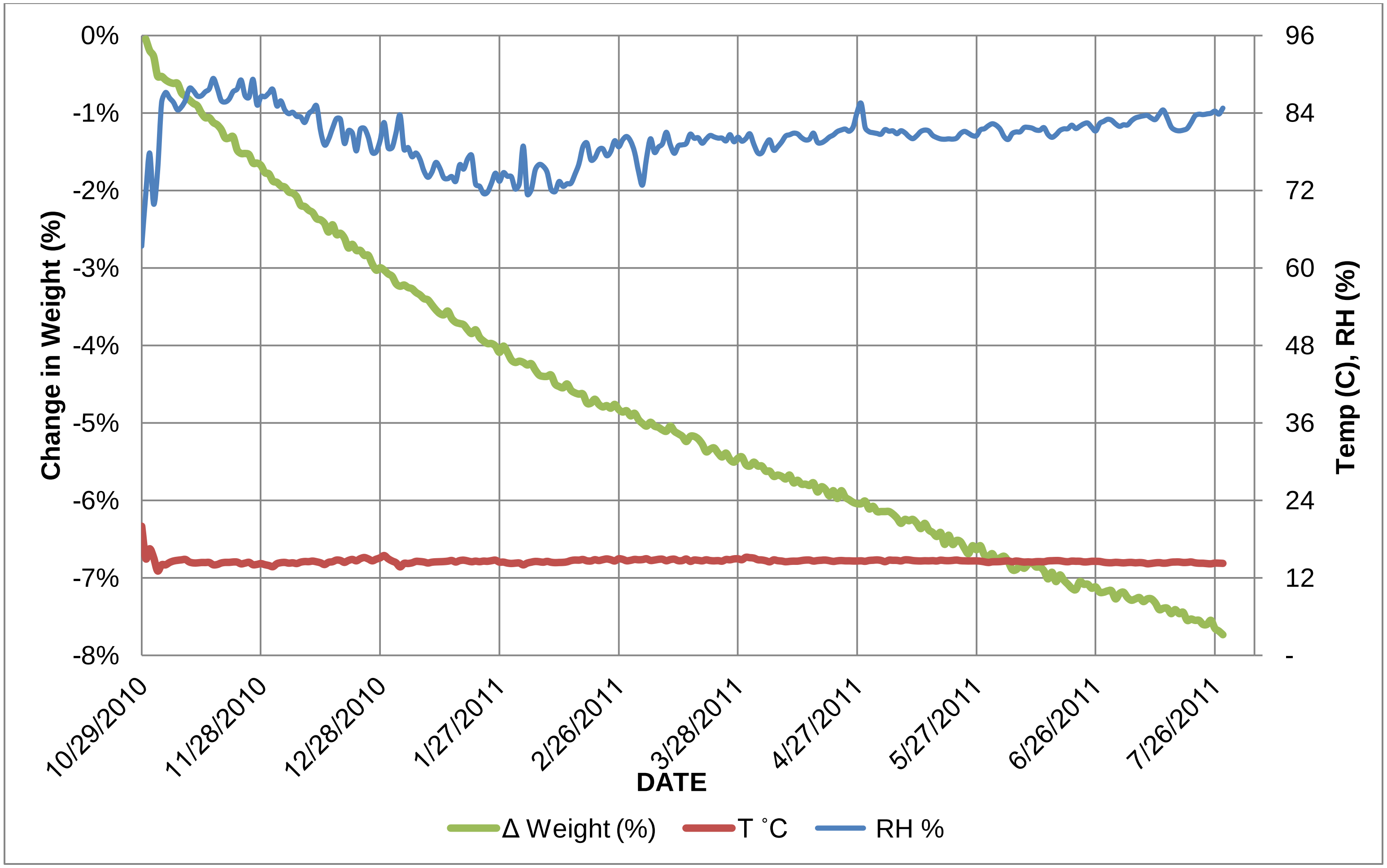

Figure 3.8: Tull Hill Farms 2011 Storage season Results

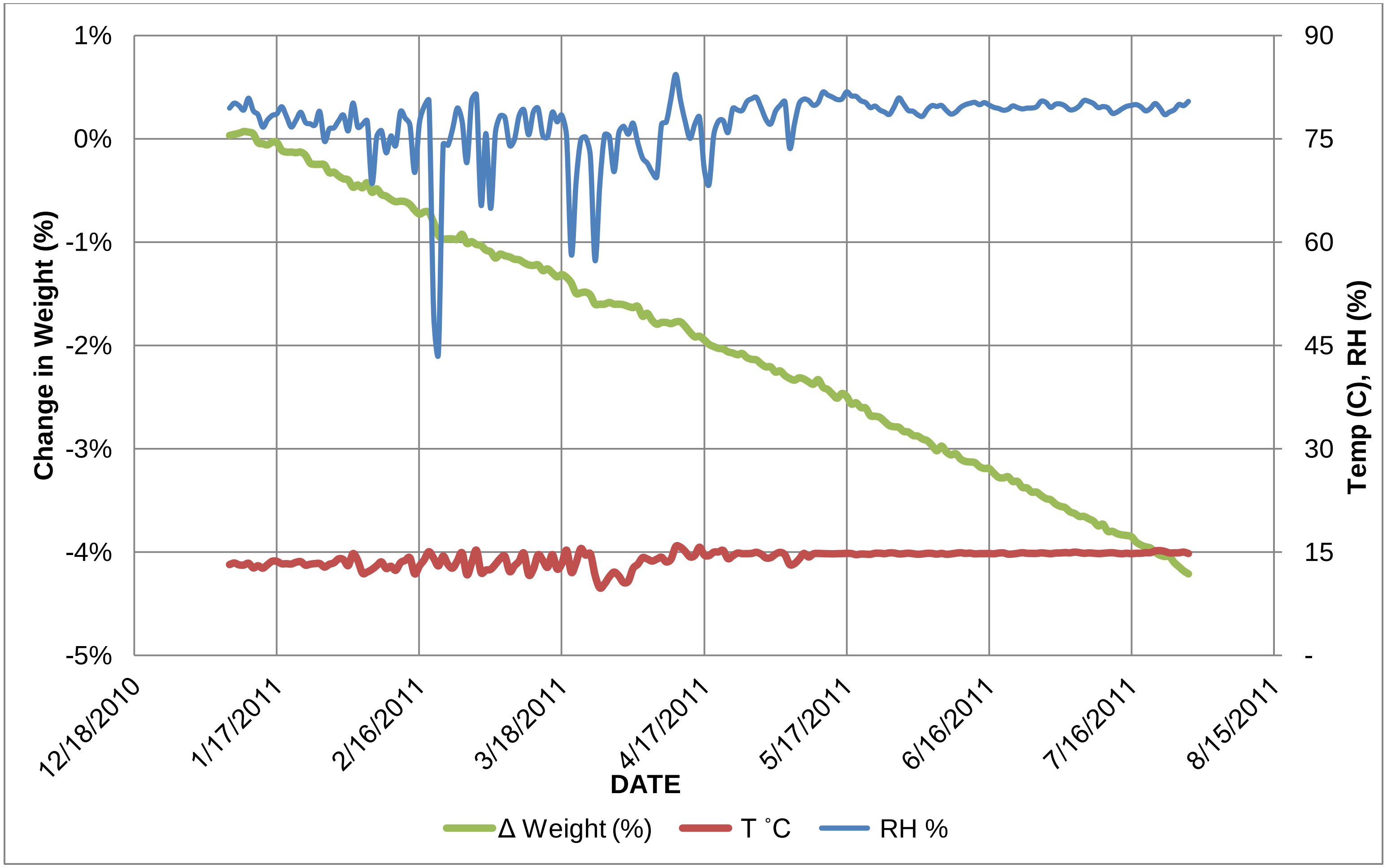

Figure 3.9: Rose Farms 2011 Storage season Results

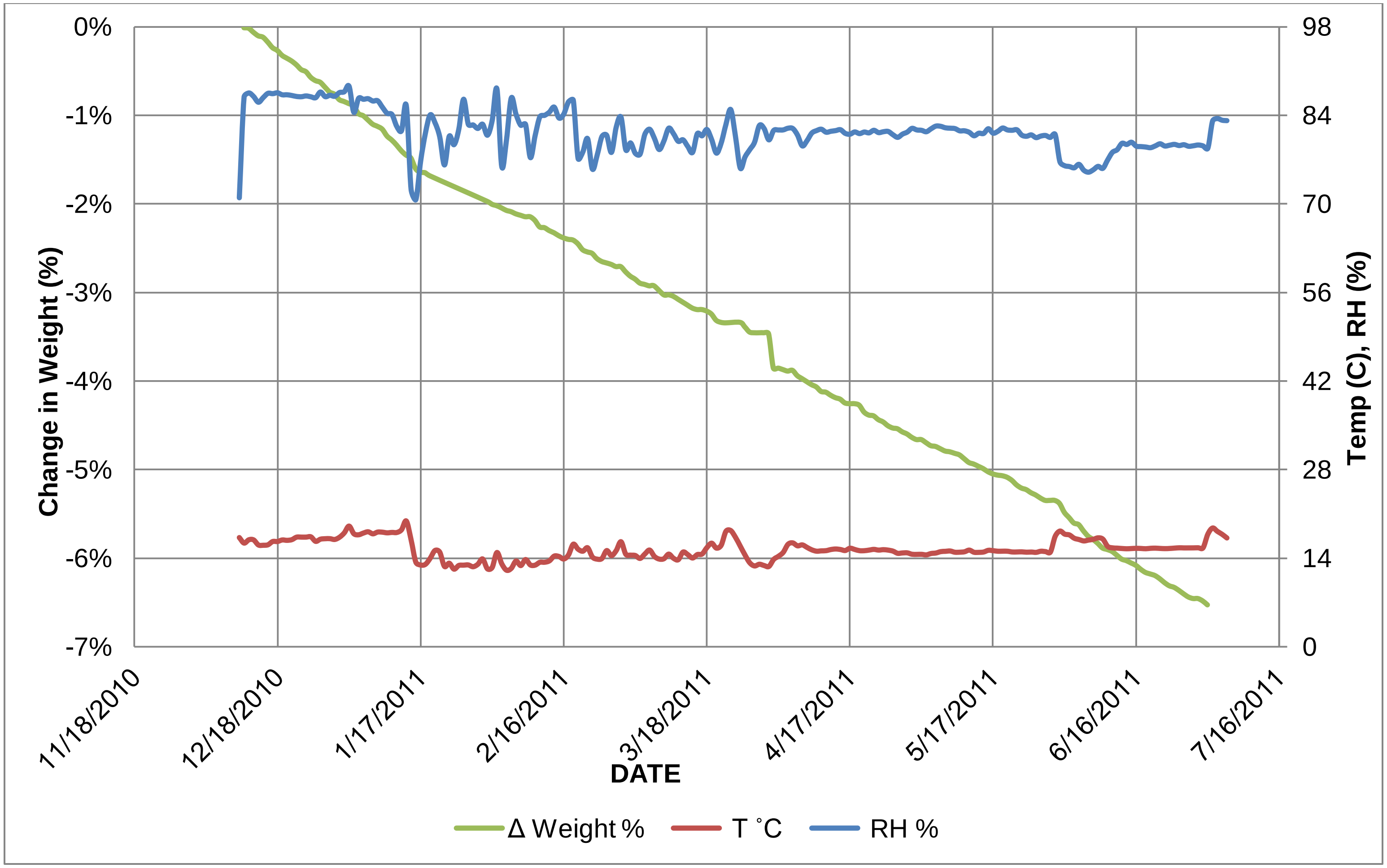

Figure 3.10: Barnes Farms 2011 Storage season Results

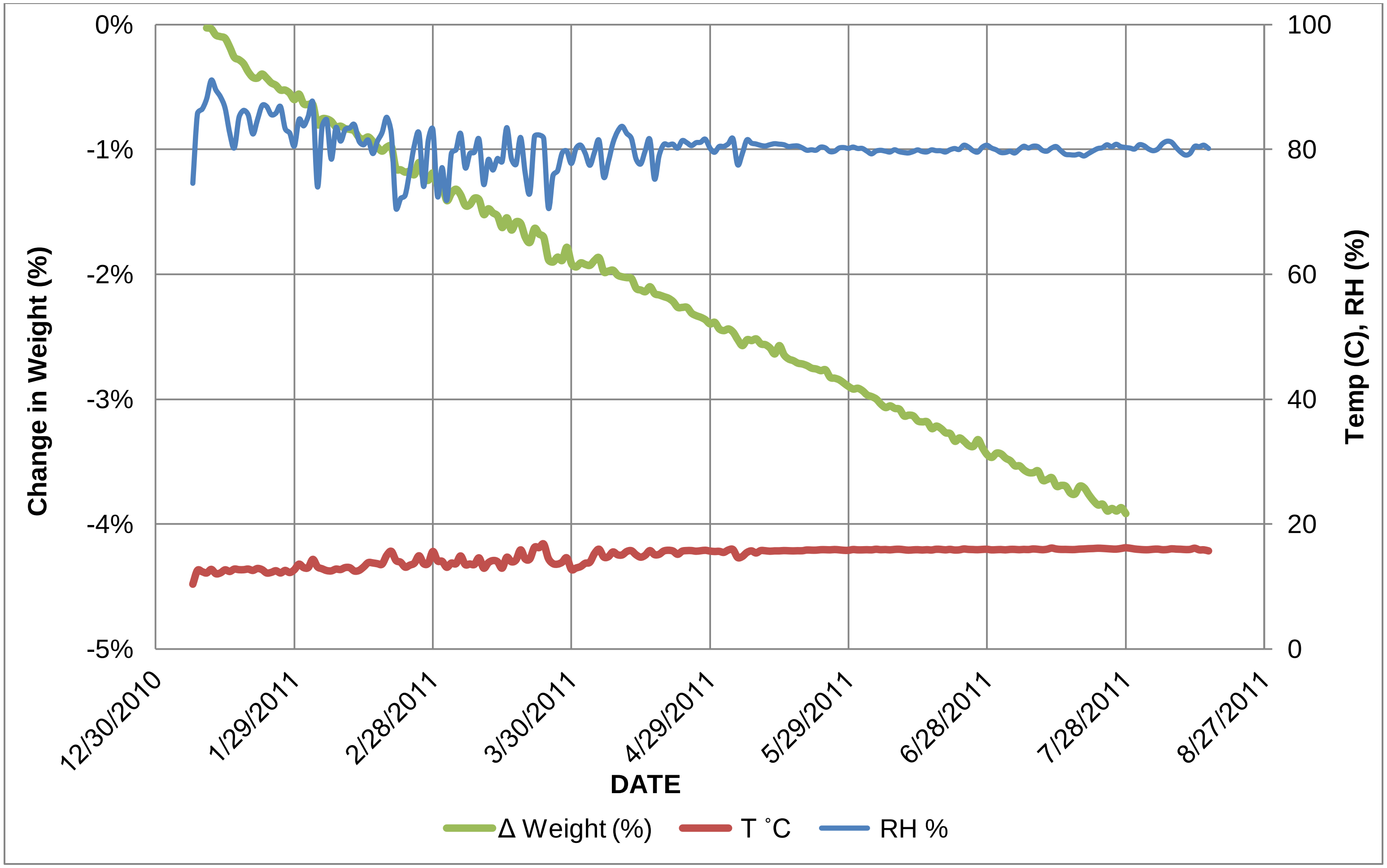

Figure 3.11: Warren Farms 2011 Storage season Results

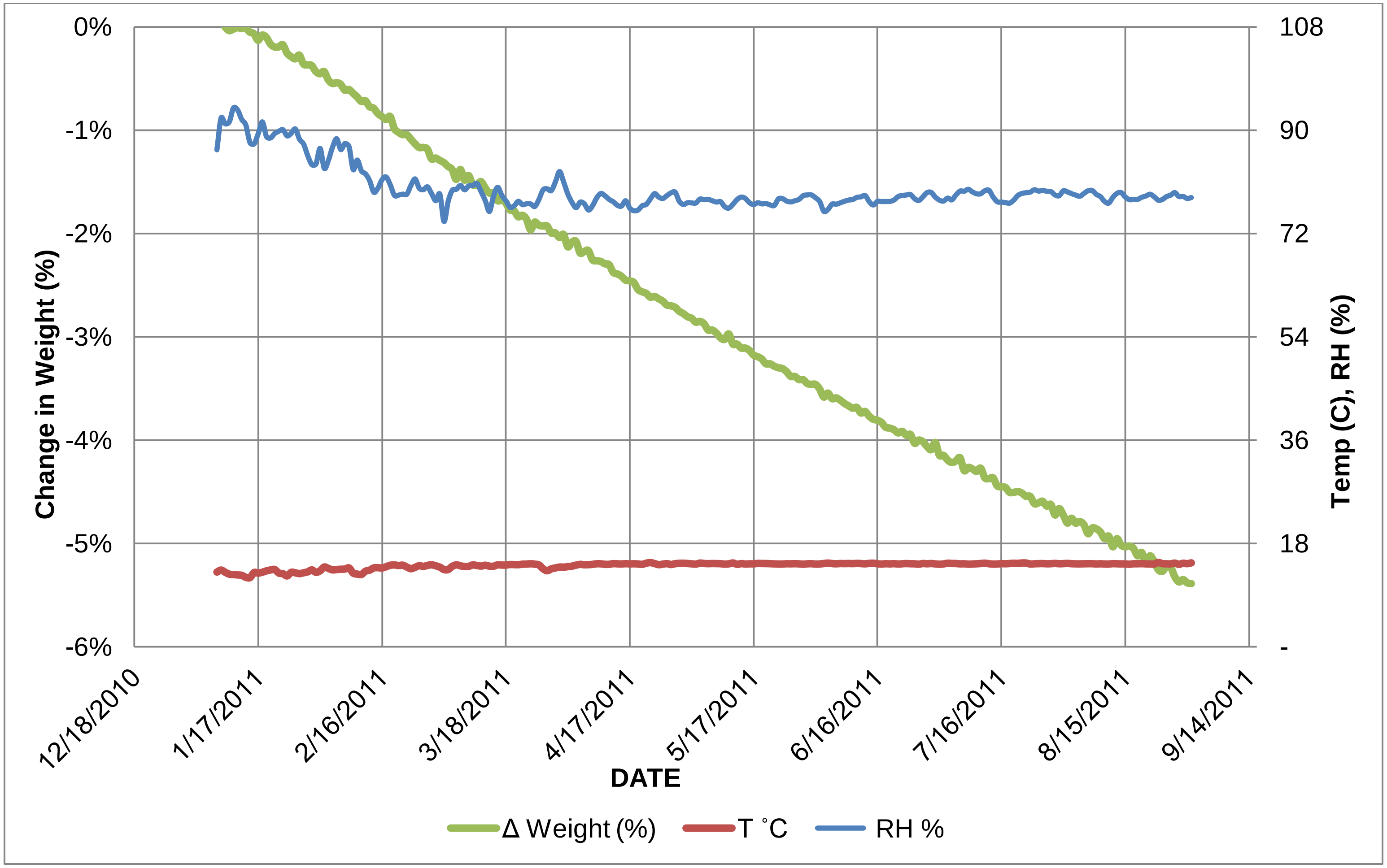

Figure 3.12: Vick Farms 2011 Storage season Results

3.4 Statistical Analysis

The importance of the statistical analysis in this study is critical. The hypothesis that this study is attempting to prove is that sweetpotato roots with similar characteristics respond differently to changes in the environment during long term storage periods. For this reason the analysis hereafter has the purpose of identifying and evaluating the results in order to establish if the different varieties are statistically different. The analysis was done in the statistical software SAS, (SAS Institute, Inc., Cary, NC). The analysis started by creating linear models with mixed effects, where the variable that was analyzed was the weight loss percentage per variety per day in an analysis of variance (ANOVA) test. Another statistical analysis is a pair wise comparison, which was done using the Tukey's Studentized Range (HSD) with a 95% confidence interval or 0.05 level. The last statistical test was Duncan grouping at 0.05 level. The weight loss percentage was converted into normalized values in order to run the tests. However, the fact that the general linear model, ANOVA, Tukey and Duncan analysis use means of the data for their calculations, dilute in some degree the results. This is especially true when compared to the results obtained when total values are used in the numerical analysis. Therefore the differences that are visible in the analysis correspond to the use of a different parameter, average instead of total values. Nevertheless the order in which the sweetpotato varieties performed is the same in both analyses (numerical and statistical) for 2010 and slightly different in 2011. In the 2011 storage season statistical analysis, the ranking of the varieties is the same as it is in the numerical analysis with the exception of the varieties "Carolina Rose" and "Hatteras". These which are last and second to last in the numerical analysis respectively and for the statistical analysis results, their order is reversed.

Separate but similar models were fit for 2010 and 2011. The experimental material was somewhat different from one year to the next due to different sources of sweet potatoes. As it was explained above, during the 2010 storage season, sweetpotatoes from the breeding program at NCSU were collected for the experiment. For the 2011 storage season, sweetpotatoes were planted specifically for this project. However, due to the variability of agricultural commodities, even if there is the attempt of controlling as many factors as possible, each iteration of the experiment would count with different material. Therefore the fact of having two different sources for the material used during the two storage seasons would make the results of the experiment stronger, and would reflect the strength of genotype on ruling the behavior of sweetpotatoes after harvest.

The linear model included fixed effects for variety, temperature, repetition and the interaction of the three with linear dependence on day.

The statistical analyses were done for the varieties of sweetpotatoes stored under varying temperature during the storage seasons 2010 and 2011. The complete SAS output is in appendix C and D respectively. The sweetpotato variety "Evangeline" was not included in the statistical analysis of the 2011 storage season because many values were missing due to malfunctions of the electronic equipment used in the data collection.

Analysis of the results obtained by growers in commercial rooms during the storage seasons 2010 and 2011 were also conducted. In the analysis, the weight loss percentage of the sweetpotato variety “Covington” was included in order to show the differences between this variety (designated the control) stored under varying and stable conditions. The SAS output for both analysis is located in Appendix E for the 2010 exercise and Appendix F for 2011.

Inspection of the F-tests for fixed effects in the model suggests that rate of weight loss depends on both variety and temperature. Some varieties have greater rates of weight loss when temperature is elevated while others are not as susceptible to warmer temperatures. The F-ratios for the ANOVA tests are 25.13 and 9.47, for the analysis of sweetpotato varieties stored under varying conditions during 2010 and 2011, respectively; both with $p<.0001$. From the F values it is possible to see that the variability for the 2010 experiment is greater than the variability during 2011 One and a likely explanations for this phenomenon could be the different origin of the roots.

F values for the ANOVA analysis of the results obtained in commercial facilities are in 2010, 19.58, and 10.63 for the 2011 storage season, both with $p<.0001$.

The unexplained variability is reduced considerably in 2011. The estimated error variance components for the two years are MSE (2010) = 8.53, MSE (2011) = 4.29.

For the commercially stored sweetpotatoes the values are MSE (2010) = 4.66, MSE (2011) = 2.27.

Generally, the rate of weight loss is greatest for the varieties "Carolina Rose" and "Hatteras", and this persists across both years. There is some rearrangement from one year to the next among the other three. "Beauregard" and "Covington" exhibited generally low rate of weight loss that doesn't vary much from one year to the next.

"Covington" stored under commercial conditions have lower rate of weight loss than stored under varying conditions in both years.

The coefficient of variance is comparable in the four experiments, showing that the variance in the study is similar in all cases.

In table 3.3 below, it is possible to see the effect of the different components of the ANOVA analysis for the 2010 and 2011 Storage seasons.

Table 3.3: P values from the ANOVA analysis for the Sweetpotatoes Stored under varying conditions during the Storage seasons 2010 and 2011

	P values		
Source	**2010**	**2011**	
Variety	< 0.0001	< 0.0001	***
Temperature	< 0.0001	< 0.0001	***
Repetition	< 0.0001	< 0.0001	***
Var*Temp*Rep	0.0533	1.0000	

*** Effect is significant at the 0.05 level

From table 3.3, it is possible to see that variety, temperature and repetition had significant effect during both storage seasons, on the other hand the interaction of these three factors had no significant effect in both cases.

For the purpose of recognizing the difference between varieties, Tukey's Studentized Range (HSD) test was conducted at 0.05 level pair wise comparison for the sweetpotato varieties stored under varying temperature. The results are shown in the following table:

Table 3.4: Tukey's Studentized Range (HSD) test at 0.05 level, Pair wise comparison for the Sweetpotatoes Stored under varying conditions during the Storage seasons 2010 and 2011

2010		2011	
Variety Comparison		**Variety Comparison**	
Covington - Beauregard		Covington - Beauregard	***
Covington - Evangeline	***	Covington - Hatteras	***
Covington - Hatteras	***	Covington - Carolina	***
Covington - Carolina	***	Beauregard - Covington	***
Beauregard - Covington		Beauregard - Hatteras	***
Beauregard - Evangeline	***	Beauregard - Carolina	***
Beauregard - Hatteras	***	Hatteras - Covington	***
Beauregard - Carolina	***	Hatteras - Beauregard	***
Evangeline - Covington	***	Hatteras - Carolina	***
Evangeline - Beauregard	***	Carolina - Covington	***
Evangeline - Hatteras	***	Carolina - Beauregard	***
Evangeline - Carolina	***	Carolina - Hatteras	***
Hatteras - Covington	***		
Hatteras - Beauregard	***		
Hatteras - Evangeline	***		
Hatteras - Carolina	***		
Carolina - Covington	***		
Carolina - Beauregard	***		
Carolina - Evangeline	***		
Carolina – Hatteras	***		

******* Comparisons significant at the 0.05 level

From the table above it is possible to see that the difference between varieties is statistically different at the 0.05 level. The only two varieties that are not different are Beauregard and Covington during season 2010, which is comparable to the data obtained in the numerical analysis. This may be due to their close genetic relationship. These results are comparable with the results from the Duncan grouping test at the same level, which appear in table 3.5

Table 3.5: Duncan's Multiple Range Test at 0.05 level for the Sweetpotatoes Stored under varying conditions during the Storage seasons 2010 and 2011

2010		2011	
Variety	**Duncan Grouping**	**Variety**	**Duncan Grouping**
Covington	A	Beauregard	A
Beauregard	A	Covington	B
Evangeline	B	Carolina Rose	C
Hatteras	C	Hatteras	D
Carolina Rose	D		

NOTE: Varieties with the same letter are not significantly different

The difference between the sweetpotato variety "Covington" stored under varying conditions and stored under commercial conditions is statistically significant. The results obtained in the Duncan's test for both storage seasons, and in the HSD pair wise comparison for the 2011 season when there was more than one commercial grower were also statistically significant. In all the cases, the roots stored under varying temperature had a greater weight loss rate than those stored under stable conditions. Commercial growers are identified by their name, but all of them produce and store the variety “Covington”. These results are detailed in the tables below:

Table 3.6: Duncan's Multiple Range Test at 0.05 level for the Sweetpotatoes variety “Covington” Stored under varying conditions and Commercial Conditions during the Storage seasons 2010 and 2011

2010		2011	
Variety	**Duncan Grouping**	**Variety**	**Duncan Grouping**
Tull Hill	A	Rose	A
Covington	B	Warren	A
		Vick	B
		Barnes	C
		Tull Hill	D
		Covington	E

NOTE: Varieties with the same letter are not significantly different

Table 3.7: Tukey's Studentized Range (HSD) test at 0.05 level, Pair wise comparison for the Sweetpotatoes variety "Covington" Stored under varying conditions and Commercial Conditions during the Storage seasons 2011

2011	
Variety Comparison	
Covington - Rose	***
Covington - Warren	***
Covington - Vick	***
Covington - Barnes	***
Covington – Tull Hill	***

******* Comparisons significant at the 0.05 level

3.5 Discussion

The roots used for the study during the 2010 season were from different origin than those used during the 2011 storage season because of logistic and timing conditions. However, the results presented in figure 3.5 and 3.6, which is the product of the collected data shown in figure 3.3 and 3.4, show that “Beauregard” and “Covington” lost the least amount of weight during both experiments. It Also shows that “Carolina Rose” and “Hatteras” lost more weight, followed by “Evangeline”. The difference between the material used in the experiments is also evident in the statistical analysis, where the estimated error variance components for the two years are MSE(2010)= 8.43, MSE(2011)=4.29, which means that the variability of the data was higher in 2010, compared to the MSE value from 2011 storage season. The difference is visible throughout the statistical analysis, but the results are consistent in both storage seasons as it is shown in Table 3.4 and Table 3.5. These results show the strong genetic component in the behavior of sweetpotatoes under different environmental conditions. Therefore the most important factors in determining the respiration rate during long term storage are internal rather than external; nevertheless, external factors play a crucial role in the results of long term storage of sweetpotatoes. This is evident when we compare the weight loss of sweetpotatoes in commercial facilities under stable environmental conditions against the results of sweetpotatoes stored under variable conditions.

3.6 Conclusions

P values in Table 3.3 for fixed effects in the model suggests that rate of weight loss depends on both variety and temperature. That is, the dependence of rate of weight loss on temperature itself varies across varieties, showing the strong relation between genotype and susceptibility to environmental conditions. The variability was greater in 2010 as it is shown in the F values and MSE.

The rate of weight loss was greater for the varieties “Carolina Rose” and “Hatteras” during both years.

“Beauregard” and “Covington” were the two varieties that had the lowest susceptibility to temperature, having the smallest rate of weight loss and the smallest slope (rate of change) during both storage seasons. “Evangeline” was intermediate between the two groups.

Commercial facilities had comparable results, which was to be expected since all of them cultivate the same sweetpotato variety (“Covington”) and all the facilities are equipped with comparable NHV storage facilities. The results obtained from commercial facilities served to contrast the results obtained by the same cultivar under variable conditions, showing the importance of controlling environmental factors. The statistical analysis agrees with this conclusion and results are shown in Table 3.6 and Table 3.7.

Variety selection and environmental conditions are the key factors to success when storing sweetpotatoes long term.

Chapter 4

Sweetpotato Respiration Rate

4.1 Introduction

Sweetpotatoes (*Ipomoea batatas* (L) Lam) have been classified as a tropical underground vegetable; a storage root with low respiration rates (Kader, et al. 2002). This classification is important, especially for the postharvest practices because they arestorage organs. They are principlly composed of carbohydrates with a naturally long shelf life. (Kader, et al. 2002). After harvest sweetpotatoes continue respiring, therefore the effectiveness of the storage conditions in extending shelf life can be evaluated by measuring the respiration rates (Bower, et al. 1998).

Sweetpotatoes are produced and consumed in most countries of the world. They are utilized basically in three ways; as food, feed, or starch production (Bouwkamp, 1985). Sweetpotaoes is the 7th most important food crop in the world (Kays, 2004).

The importance of the respiration rate lies in the fact that it is an indicator of the overall rate of metabolism (Kays, 2004). The most basic explanation of this process is that “it is the mechanism that living cells use to release energy through the breakdown of carbon compounds, which are converted into carbon skeletons necessary for maintanence and synthetic reactions after harvest" (Kays, 2004). Sweetpotatoes are very low producers of ethylene, a ripening hormone, emitting $<0.1\ \mu l \bullet kg^{-1} \bullet hr^{-1}$ at 20 ˚C (Kader, et al. 2002;Kays, 2004). Other volatile compounds are also produced in extremly low ammounts, therefore the production of those gases are neglegible for the calculation of respiration rates. Another product of respiration is thermal energy in the form of heat, which is called vital heat or respiration heat and contributes to the refrigeration load in the stirage facility(Salveit, 2004; Boyette, Wilson and Estes, 1994). It is important to remove that heat because failing to do so will raise the temperature inside the storage room, which will cause an increase in the respiration rate (a positive feedback loop) and a subsequent reduction in the shelf live of the sweetpotatoes. Therefore keeping a low respiration rate will maintain other metabolic reactions low as well. This practice will contribute to maintain the quality, reduce shinkage and extend the shelf life of sweetpotatoes. The factors which affect respiration rates of sweetpotatoes after harvest are largely internal (Salveit, 2004), therefore the necessity of comparing how the genotype of sweetpotato cultivars contribute to the success of long term storage.

There are several external aspects that affect the respiration rate of sweetpotatoes during long term storage, one of them is temperature. The increase on respiration rate due to temperature is measured by the temperature quotient, for every interval of 10 ˚C, which is called the Q_{10} (Salveit, 2004). Other factors affecting respiration are chilling stress and heat stress. In sweetpotatoes chilling stress occur when the roots are exposed to temperatures below 10 to 12 ˚C or 50 to 53.6 ˚F (Salveit, 2004). Heat stress occurs when sweetpotatoes are exposed to very high temperatures and the quotient of respiration rate becomes negative. Other factors that influence respiration rates are the concentration of O_2 and CO_2 in the storage room (Salveit, 2004; Kays, 2004). Treatments like control atmosphere (CA) and modified atmosphere (MA) can control the concentration of gases. Another possible treatment is gamma irradiation but it has little effect extending the shelf life of sweetpotato along with CA and MA, when compared with the results of maintaining proper storage temperature (Kays, 2004). Therefore there is no commercial use of these technologies in sweetpotato storage. However it is important to keep these possibilities in mind as new markets and new discoveries emerge.

Respiration rates can be measured in different ways, but it lies in the ability of measuring the consumption of substrates, or the production of compounds (Salveit, 2004). The measurement one of the variables above gives some indication of the metabolic reactions taking place inside the sweetpotato. One of the most common strategies is to measure the production of CO_2. Another less common technique is to measure the absorption of O_2. A possible innovative technique that can be employed to measure either or both of those gasses is the use of a “respirometer”, which measures the consumption of O_2 utilizing sensors and replenish the gas in order to avoid changes in the air concentration (Bower,et al. 1998). A gas concentration can be measured in two different ways. The first is by letting a flow of air with known concentrations of O_2 and CO_2 pass through the container where the fruit or vegetable is, and then it is collected and the subsequent concentrations of O_2 and/or CO_2 are measured; the difference would be the result of respiration. This system is dynamic and can record changes in the respiration rate over time. (Bower, et al. 1998) (Salveit, 2004).

The second system consists of placing the fruit or vegetable in an enclosure with a known concentration of O_2 and/or CO_2, and after a determined amount of time, the air inside the enclosure is sampled. The gas concentration from the sample is measured to establish the difference with the original concentration. This difference will be the respiration rate per unit of weight and unit of time. This system is known as static. In general it is easier to measure CO_2, because changes in O_2 concentration are small compared to the total concentration (Bower, et al. 1998).

Another way of calculating the respiration rate is by measuring the loss of substrate, which represent the loss of dry weight. For commodities like sweetpotatoes which need to survive long storage terms, the loss of dry weight due to respiration can be significant (Salveit, 2004).

The loss of substrate, consumption of oxygen, production of carbon dioxide and heat are expressed in the following respiration equation:

$$C_6H_{12}O_6 + 6O_2 + 6H_2O \rightarrow 6CO_2 + 12H_2O + 673\ kcal \qquad (4.1)$$

Reported respiration rates in sweetpotato vary greatly, but most investigators agree that sweetpotatoes have very low respiration rates as compared to fast growing tissue and many fruit and vegetables. Cantwell and Suslow, (2001) reported for cured sweetpotato at 10 °C, a respiration rate of 7 ml $CO_2 \bullet kg^{-1} \bullet hr^{-1}$ and at 15 °C 0 to 12 ml $CO_2 \bullet kg^{-1} \bullet hr^{-1}$. Hardenburg et al. (1986), reported that the respiration rate of cured sweetpotatoes at 15 to 16 °C is 20 to 24 mg $CO_2 \bullet kg^{-1} \bullet hr^{-1}$. Reported respiration rates for cured sweetpotatoes at different temperatures by Stewart, et al. (2000) are listed in the following table:

Table 4.1: Cured Sweetpotato Respiration Rates at different Temperatures (Stewart, Farkas, Blankenship, Boyette, 2000)

VARIETY	**TEMPERATURE °C**			
	15	**20**	**25**	**30**
	mg $CO_2 \bullet kg^{-1} \bullet hr^{-1}$			
Beauregard	8.70	10.18	26.88	27.74
Hernandez	11.35	15.27	32.83	32.50
Jewel	11.94	12.58	31.75	38.17

From the respiration rate (R_{rt}) we can find respiration heat (R_{ht}) (Stewart, et al. 2000). According to Hardenburg et al. (1986), 2.55 calories or 10.676 J of energy is released to the atmosphere per mg of CO_2 emitted during respiration; therefore we can calculate the R_{ht} by multiplying the R_{rt} by 10.676 $J \bullet mg^{-1}$(equation 4.2). Cantwell and Suslow, 2001, recommend that R_{ht} can be calculated by multiplying ml $CO_2 \bullet kg^{-}$

$^{1} \bullet hr^{-1}$ by 440 to get Btu•ton^{-1}•day^{-1} or by 122 to get kcal•metric-ton^{-1}•day^{-1}. In order to standardized the calculations from the R_{rt} in milligrams, it is necessary to convert the factors reported by Cantwell and Suslow, 2001 in milliliters to milligrams of CO_2, by multiplying them by the CO_2 density at atmospheric pressure which is 1.96 mg•ml^{-1} , thus the following factors can be establish for R_{rt} in mg CO_2•kg^{-1}•hr^{-1}:

$$R_{ht}(J \bullet kg^{-1} \bullet hr^{-1}) = 10.676 R_{rt} \tag{4.2}$$

$$R_{ht}(Btu \bullet ton^{-1} \bullet day^{-1}) = 862.4 R_{rt} \tag{4.3}$$

$$R_{ht}(kcal \bullet metric\ ton^{-1} \bullet day^{-1}) = 239.12 R_{rt} \tag{4.4}$$

The objective of this present study is to calculate the respiration rate (R_{rt}) of cured roots from five commercially grown sweetpotato varieties, 'Beauregard", "Carolina Rose", "Evangeline", "Hatteras" and "Covington" during long term storage. R_{rt} will be calculated based in the consumption of glucose as substrate. The glucose consumed will be calculated from the dry weight change during the storage periods. The experiment was conducted at two scales. The first one was at laboratory scale with approximately 20 kg per variety per repetition. During the lab experiment the sweetpotatoes had been stored at four temperature ranges: 14.4 - 16.6°C, 16.7 - 18.8°C, 18.9 - 21.1°C, 21.2 - 23.3°C. The second was a commercial scale study. with approximately 6,900 kg per repetition. The cured roots were the sweetpotato cultivar "Covington". The commercial experiment was replicated at five different grower facilities at recommended temperature ranges 14.5 ±1˚C.

4.2 Methods

Measuring respiration rates has been largely considered as a very important postharvest indicator of metabolic activity inside fruits and vegetables after they are detached from the plant. Measuring the production of CO_2 or the consumption of O_2 in static and dynamic ways have been the most common ways of calculating the R_{rt}. Another method is measuring the loss of substrate from a commodity to the environment. In order to calculate the R_{rt} during long term storage of sweetpotatoes, the method that is employed here is the loss of substrate method. The substrate is assumed to be entirely glucose, a hexose sugar that is the basic substrate for the respiration reaction expressed in equation 4.1. The method used and the assumption made is explained in the following paragraphs.

To calculate the substrate loss to the environment due to respiration, it is necessary to monitor the weight over time of the sweetpotatoes plus the environmental conditions and the dry matter percentage content. For this purpose a data acquisition system was design and built specifically for collecting the weight of the sweetpotatoes in two circumstances. The first was a lab scale study were five sweetpotato varieties were in plastic lugs with a total gross weight of approximately 20 kg. They were placed over bending beam load cells sensors with a maximum capacity of 30 kg. Each variety was replicated 4 times, and the experimental design was complete randomized block (CRB). The second condition is a commercial scale experiment, where a platform with four load cell sensors with the capability to measure up to 2,273 kg (5,000 lb) for each sensor, giving a total of 9,100 kg (20,000 lb) per platform. One platform was placed in commercial storage rooms equipped with NHV systems during 2010. Five platforms of the same characteristics were built and installed for the 2011 storage term. Each platform was located in a different commercial facility. All of the commercial storage rooms that participated in this study were equipped with NHV storage systems.

In both conditions described above, weight, temperature and RH was recorded hourly in data loggers and then it was collected and analyzed in the computer utilizing specialized software. The data was collected during two storage periods. The first period was from December 2009 to September 2010. This period is referred to as the 2010 storage term. The second period was from December 2010 to September 2011 and this period is referred to as the 2011 storage term.

For the 2010 storage term there were two different locations. One was a lab-scale study conducted in a controlled environment room on-campus. The second location was a commercial storage room in Tull Hill Farms, located in Kinston, NC. For the lab-scale experiment the sweetpotatoes roots that were tested were from the five commercial varieties: “Beauregard”, “Evangeline”, “Covington”, “Carolina Rose”, and “Hatteras”. All those varieties are of similar characteristics, are primarily for fresh consumption and have orange flesh and skin color. They were collected from the breeders at North Carolina State University, therefore, the conditions in which they were grown, wasn’t controlled. However they were cured in the cure-storage rooms at the Horticultural Crops Research Station in Clinton, NC. The curing conditions were 29.4 °C (85 °F) and 85% RH for 7 days. They were then taken to the controlled environment room on-campus at NCSU in Raleigh, NC. Eighty kg of sweetpotatoes grading U.S. No. 1 were selected and placed in plastic lugs of approximated 20 kg each. Each lug was placed on individual load cell sensors. The experimental design for this study was 5 varieties, and 4 repetitions, arranged as a Complete Randomized Block (CRB). The study had three identical temperature cycles from 14.5 to 23.3˚C (58 to 74˚F), each temperature point was maintained for two weeks.

The temperature intervals were kept only two weeks long in order to avoid sprouting of the sweetpotatoes, after being at temperatures above storage recommendation (14.5˚C). Temperature intervals started at the recommended, then the roots were exposed to the next temperature level, then the temperature was lowered again, and so on until completing the cycle.

In order to reduce variability for the 2011 storage season, the sweetpotatoes were produced at the Lower Coastal Plain Tobacco Research Station located in Kinston, NC. The sweetpotato roots were harvested on September 20th, 2010. The sweetpotatoes from the five varieties were hand harvested and placed in 20 bushels bins. Each variety was clearly identified, and transported to the Horticultural Crops Research Station in Clinton, NC, were they were cured at 29.4 °C (85 °F) and 85% RH for 7 days. After curing they were transported to the NCSU campus controlled environment room 28, located in Kilgore Hall. The roots then were placed under the same conditions as sweetpotatoes during the 2010 storage season.

During the 2010 storage season there was only one commercial grower who participated in the study, It was Tull Hill Farms located in Kinston, NC. The sweetpotatoes used for the study were harvested on October, 2009. The data for the study started to be recorded on December 16th, 2009 until July 29th, 2010. The variety used was “Covington”, and the experiment was conducted in storage room 2. The temperature and RH were kept stable and they were recorded during the same dates. Tull Hill farms also repeated the study for the 2011 Storage season, during that season the sweetpotatoes were harvested on October, 2010. The data for the study started to be recorded on October 30th, 2010 until July 28th, 2011. The variety used was “Covington”, and the experiment was conducted in storage room 2 as well. The temperature and RH were kept stable and they were recorded during the same dates.

Through the 2011 Storage season five commercial growers located in central North Carolina collaborated with the study. One of them was Tull Hill farms, whose conditions are described in the paragraph above. The second commercial storage room that took part of the study was located in Rose Farms in Spring Hope, NC. The sweetpotatoes used for the study were harvested on October 15th, 2010. The data for the study started to be recorded on January 7th, 2011 until July 28th, 2011. The variety used was Covington, and the experiment was conducted in storage room 2.

Temperature and RH were kept stable and they were recorded during the same period.

Barnes Farms, located in Spring Hope, NC, is another collaborator for this project. The sweetpotatoes used for the study were harvested there on October 20th, 2010. The data for the study started to be recorded on December 10th, 2010 until July 5th, 2011. The variety used was “Covington”, and the experiment was conducted in storage room 16. Temperature and RH were kept stable and they were recorded during the same dates.

Warren Farms, located in Clinton, NC, also collaborated with this study. The sweetpotatoes used for the study were harvested there on October 21st, 2010. The data for the study started to be recorded on January 7th, 2011 until July 28th, 2011. The variety used was “Covington”, and the experiment was conducted in storage room 4. Temperature and RH were kept stable and they were recorded during the same period.

Vick Farms, located in Wilson, NC, is the fifth commercial sweetpotato grower that participated in this study; the sweetpotatoes used for the study were harvested on October 27th, 2010. The data for the study started to be recorded on January 9th, 2011 and concluded on August 31st, 2011. The variety used was “Covington”, and the experiment was conducted in storage room 2. Temperature and RH were kept stable and they were recorded during the same dates.

After collecting the weight of the sweetpotatoes over time, the other parameter necessary for the calculations was the dry matter percentage. During the 2010 storage season, three samples per repetition per variety of sweetpotatoes were collected after ten months of storage. Each sample was composed of two roots randomly selected; the dry matter content was determined by the quotient of the fresh weight by the dry weight. The roots were dried in a lyophilizer or freeze dryer, the results are in table 4.2.

Table 4.2: 2010 Storage Season Dry Matter Content

VARIETY	MONTHS STORED	DRY MATTER PERCENTAGE
Beauregard	10	15.8%
Carolina Rose	10	17.5%
Covington	10	18.6%
Evangeline	10	21.1%
Hatteras	10	17.8%

During the 2011 Storage season, three samples per variety of sweetpotatoes were collected after three, seven, ten, and eleven, months of storage. Each sample was composed of two roots randomly selected. Also three samples per each commercial scale study were taken at two, three, five, seven, and nine, months of storage. The dry matter content was determined by the quotient of the fresh weight by the dry weight, the roots were dried in a lyophilizer or freeze dryer, the results are in the following tables:

Table 4.3: 2011 Storage Season Dry Matter Content for Five Sweetpotato Varieties

VARIETY	MONTHS STORED	DRY MATTER PERCENTAGE
Beauregard	3	22.2%
	7	21.5%
	10	21.0%
	11	18.6%
	Average	**20.8%**
Carolina Rose	3	23.0%
	7	20.9%
	10	22.5%
	11	20.4%
	Average	**21.7%**
Covington	3	23.5%
	7	21.9%
	10	22.5%
	11	19.6%
	Average	**21.9%**
Evangeline	3	25.4%
	7	21.3%
	10	26.2%
	11	19.3%
	Average	**23.1%**
Hatteras	3	22.9%
	7	22.6%
	10	22.1%
	11	18.3%
	Average	**21.5%**

Table 4.4: 2011 Storage Season Dry Matter Content for Five Commercial Growers of Sweetpotatoes Variety Covington

VARIETY	MONTHS STORED	DRY MATTER PERCENTAGE
Barnes Farms	2	23.0%
	3	----*
	5	20.2%
	7	19.2%
	9	19.7%
	Average	**20.5%**
Rose Farms	2	20.7%
	3	----*
	5	18.6%
	7	19.3%
	9	18.3%
	Average	**19.3%**
Tull Hill Farms	2	19.5%
	3	20.1%
	5	18.5%
	7	19.0%
	9	22.5%
	Average	**19.9%**
Warren Farms	2	21.2%
	3	22.1%
	5	19.2%
	7	18.9%
	9	18.6%
	Average	**20.0%**

*Samples were lost due to lyophilizer malfunction

The dry matter percentage of sweetpotato stays constant through the storage periods at 20±2%, (explain why) thus in order to calculate the respiration rate for each case the dry percentage that will be employed is the season average of each variety or each grower.

Therefore the weight loss is calculated with the following equations:

$$weight_j - weight_i = \Delta weight \tag{4.5}$$

The result from equation 4.5 is the change in weight over a period with upper limit j , and lower limit *i*. Then the result of equation 4.5 is multiplied by the percentage of dry matter, the result is the dry weight loss:

$$\Delta weight \cdot \%\, Dry\ matter = \text{Dry weight loss} \tag{4.6}$$

In order to calculate the respiration rate from the dry weight loss, it is necessary to assume that the complete mass of the substrate is glucose. With this in mind, it is necessary to describe the composition and respiration process inside the sweetpotato. The composition of sweetpotatoes varies according to variety, climatic conditions, and duration of storage, but an average composition is presented in the table 4.5:

Table4.5: Chem. Composition of Sweetpotato Roots (Salunkhe, & Kadam 1998)

Content	Source A	Source B
Moisture (%)	50-80	72.84
Total carbohydrates (%)	----	----
Starch (%)	15-29	24-28
Protein (%)	0.5-2.4	1.65
Ether Extract (%)	1.0-6.4	0.30
Fiber (%)	----	----
Reducing Sugars (%)	0.5-2.5	0.85
Non-starch (%)	1.0-7.5	----
Mineral Matter (%)	0.9-1.4	0.95
Carotene (mg/100 g)	1-12	----
Thiamine (mg/100 g)	0.1	0.066
Riboflavin (mg/100 g)	0.6	0.147
Nicotinic Acid (mg/100 g)	0.9	0.674
Ascorbic Acid (mg/100 g)	20-30	22.7
K (mg/100 g)	373	204
P (mg/100 g)	49	28
Ca (mg/100 g)	30	22
S (mg/100 g)	29	----
Mg (mg/100 g)	24	10
Na (mg/100 g)	13	13
Fe (mg/100 g)	0.8	0.59
Zinc (mg/100 g)	----	0.28
Copper (mg/100 g)	----	0.169
Manganese (mg/100 g)	----	3.555
Vitamin A (IU/100 g)	----	20063
Food energy (kJ/100 g)	----	441

Source A: Purcell, A.E. and M.W. Walter, Jr. Stability of Amino acids during cooking and processing of the sweet potatoes, J. Agric, Food Chem. 28:443 (1982)
Source B: Sistrunk, W.A., Miller, J.C., and Jones, L.G. Carbohydrate Changes during storage and cooking of sweet potatoes, Food Technol. 8:223 (1954)

From table 4.5 it is possible to perceive that the only two sources of energy available for respiration are reducing sugars and starch. Reducing sugars are mostly glucose. Starch will react with amylase and starch-phosphorylase to form glucose-1-phosphate in both cases. Glucose kinase, or hexose phosphate isomerase, will be transformed into glucose-6-phosphate (Kays, 2004); this last compound will enter in the glycolysis process and then complete the respiration cycle described in equation 4.1.

From equation 4.1 the substrate, glucose $C_6H_{12}O_6$, produces 6 molecules of carbon dioxide CO_2. Using the atomic weights of the elements involved in this reaction, 180 g of glucose are lost for each 264 g of carbon dioxide produced. Therefore the rate of dry weight loss can be estimated as follows: Dry weight loss ($g \bullet kg^{-1} \bullet hr^{-1}$)=mg $CO_2 \bullet kg^{-1} \bullet hr^{-1}$ x $0.68x10^{-3}$ $g \bullet mg^{-1}$ (Saltveit, 2011). This analysis can be used to find the respiration rate as production of CO_2:

$$\text{Dry weight loss}(\mathrm{g} \bullet \mathrm{kg}^{-1} \bullet \mathrm{hr}^{-1}) \div 0.68\mathrm{x}10^{-3}(\mathrm{g} \bullet \mathrm{mg}^{-1}) = mg\ CO_2 \bullet \mathrm{kg}^{-1} \bullet \mathrm{hr}^{-1} \quad (4.7)$$

Applying equation 4.7 the respiration rates of sweetpotatoes in the study were calculated for the following temperature ranges:

Table 4.6: Temperature ranges for Respiration Rate calculations

	˚F	˚C
1	58 62	14.4 - 16.6
2	62.1 66	16.7 - 18.8
3	66.1 70	18.9 - 21.1
4	70.1 74	21.2 - 23.3

4.3 Results

4.3.1 Variable Temperature

Table 4.7 represents the average of the respiration rates. The respiration rates were calculated based on the weight loss of sweetpotatoes measured hourly at the four temperature ranges specified in the following table.

Table 4.7: Respiration Rate for Five Sweetpotato Varieties at Different Temperature Intervals Obtained during the Storage Seasons 2010 and 2011

			2010 Average	2011 Average	Average
Variety	**Temp °F**	**Temp °C**	**mg CO_2 kg^{-1} h^{-1}**		
Beauregard	58 - 62	14.4 - 16.6	3.8	5.9	4.8
	62.1 - 66	16.7 - 18.8	4.3	7.2	5.8
	66.1 - 70	18.9 - 21.1	4.2	6.4	5.3
	70.1 - 74	21.2 - 23.3	6.4	6.4	6.4
Covington	58 - 62	14.4 - 16.6	5.4	6.4	5.9
	62.1 - 66	16.7 - 18.8	7.1	5.1	6.1
	66.1 - 70	18.9 - 21.1	7.5	7.5	7.5
	70.1 - 74	21.2 - 23.3	13.3	9.4	11.4
Hatteras	58 - 62	14.4 - 16.6	5.6	5.9	5.7
	62.1 - 66	16.7 - 18.8	7.9	7.0	7.5
	66.1 - 70	18.9 - 21.1	7.5	8.2	7.9
	70.1 - 74	21.2 - 23.3	8.4	9.3	8.9
Evangeline	58 - 62	14.4 - 16.6	5.0	7.1	6.1
	62.1 - 66	16.7 - 18.8	6.3	8.9	7.6
	66.1 - 70	18.9 - 21.1	6.0	7.7	6.9
	70.1 - 74	21.2 - 23.3	8.3	11.3	9.8
Carolina rose	58 - 62	14.4 - 16.6	6.5	5.9	6.2
	62.1 - 66	16.7 - 18.8	9.1	6.0	7.5
	66.1 - 70	18.9 - 21.1	8.0	9.9	9.0
	70.1 - 74	21.2 - 23.3	8.3	9.0	8.6

4.3.2 Commercial Facilities

The following table represents the average of the respiration rates calculated base on the weight loss of sweetpotatoes. The weight was measured hourly on sweetpotato roots variety "Covington" stored at stable temperature conditions, at the four commercial growers facilities. Temperature ranges are specified in the table.

Table 4.8: Respiration Rate for Sweetpotatoes variety "Covington" Stored in Commercial Facilities during the Storage Seasons 2010 and 2011

	Tull Hill 2010	**Tull Hill 2011**	**Warren**	**Rose**	**Vick**	**Barnes**
Temp °C	**mg CO2 kg^{-1} h^{-1}**					
14.4 - 16.6	4.3	5.7	4.6	3.2	4.3	4.0
16.7 - 18.8						4.8

4.4 Statistical Analysis

In order to establish if the differences between varieties are statistically significant, it is necessary to analyze the interaction between factors and between varieties. The analysis was done in the statistical software SAS by applying the general linear model (GLM) procedure, where the variable that was analyzed was the respiration rate per variety per day over the entire storage period. The statistical tools used in the study were the analysis of variance (ANOVA) test, also a pair wise comparison using the Tukey's Studentized range (HSD) with a 95% confidence interval or 0.05 level, and Duncan grouping at 0.05 level. Separate but alike models were fit for 2010 and 2011. The experimental material was somewhat different from one year to the next due to different sources of sweet potatoes. As it was explained in previous chapters, during the 2010 storage season sweetpotatoes from the breeding program at NCSU were collected for the experiment. For the 2011 storage season sweetpotatoes were grown specifically for this study. This analysis measures the variability of the study and the effect of the different components.

The linear model included fixed effects for variety, temperature, repetition and the interaction of variety and temperature with linear dependence on time.

Separate statistical analyses were conducted for the varieties of sweetpotatoes stored under varying temperature during the storage seasons 2010 and 2011. The complete SAS output is in Appendices G and H, respectively.

Analyzing the F-tests for fixed effects in the model suggests that respiration rate depends on both variety and temperature. The F-ratios for the ANOVA tests are 3.94 and 1.96 for the analysis of sweetpotato varieties stored under varying conditions during 2010 and 2011 respectively, both with $p<.0001$. From the F values it is possible to see that the variability for the 2010 experiment is greater than the variability during 2011, showing as well that some varieties are more susceptible to temperature than others.

In General, "Beauregard is the variety that consistently has the lowest respiration rate at every temperature interval, while "Carolina Rose" is consistently higher. "Covington" has low respiration rates up to 18.8˚C, after that level its respiration rate increases very rapidly. The increase of respiration rate of "Covington" sweetpotatoes shows that this variety has great susceptibly to high temperatures.

There is some differences in rankings from one year to the next among the varieties, but in average "Beauregard" and "Covington" exhibit generally low respiration rate.

The coefficient of variance and MSE are comparable in both years, showing that the variance in the study is similar in both cases.

In table 4.9 below, it is possible to see the effect of the different components of the ANOVA analysis for the 2010 and 2011 Storage seasons.

Table 4.9: P values from the ANOVA analysis for the Sweetpotatoes Stored under varying conditions during the Storage seasons 2010 and 2011

	P values			
Source	**2010**		**2011**	
Variety	< 0.0001	***	< 0.0001	***
Temperature	< 0.0001	***	< 0.0001	***
Repetition	0.0004	***	0.0676	
Var*Temp	< 0.0001	***	0.5544	

*** Effect is significant at the 0.05 level

Table 4.9 shows that variety, temperature, repetition and the interaction between variety and temperature had significant effect during 2010. During the storage season 2011, only variety and temperature had significant effect in the analysis. It is interesting to see that during both storage seasons, the most important factors in the analysis were variety and temperature.

For the purpose of recognizing the difference between varieties, the Tukey's Studentized Range (HSD) test was conducted at 0.05 level pair wise comparison to the sweetpotato varieties stored under varying temperature The results are in the following table 4.10.

Table 4.10: Tukey's Studentized Range (HSD) test at 0.05 level, Pair wise comparison for the Sweetpotatoes Stored under varying conditions during the Storage seasons 2010 and 2011

2010		2011	
Variety Comparison		**Variety Comparison**	
Carolina - Covington		Carolina - Covington	
Carolina - Hatteras	***	Carolina - Hatteras	
Carolina - Evangeline	***	Carolina - Evangeline	***
Carolina - Beauregard	***	Carolina - Beauregard	
Covington - Carolina		Covington- Carolina	
Covington - Hatteras		Covington - Hatteras	
Covington - Evangeline	***	Covington - Evangeline	***
Covington - Beauregard	***	Covington - Beauregard	
Hatteras - Carolina	***	Hatteras - Carolina	
Hatteras - Covington		Hatteras - Covington	
Hatteras - Evangeline	***	Hatteras - Evangeline	***
Hatteras - Beauregard	***	Hatteras - Beauregard	
Evangeline - Carolina	***	Evangeline - Carolina	***
Evangeline - Covington	***	Evangeline - Covington	***
Evangeline - Hatteras	***	Evangeline - Hatteras	***
Evangeline - Beauregard	***	Evangeline - Beauregard	***
Beauregard - Carolina	***	Beauregard - Carolina	
Beauregard - Covington	***	Beauregard - Covington	
Beauregard - Hatteras	***	Beauregard - Hatteras	
Beauregard - Evangeline	***	Beauregard - Evangeline	***

******* Comparisons significant at the 0.05 level

These results are comparable with the results from the Duncan grouping test at the same level, which appear in table 4.11

Table 4.11: Duncan's Multiple Range Test at 0.05 level for the Sweetpotatoes Stored under varying conditions during the Storage seasons 2010 and 2011

2010		2011	
Variety	**Duncan Grouping**	**Variety**	**Duncan Grouping**
Carolina Rose	A	Evangeline	A
Covington	AB	Hatteras	B
Hatteras	B	Carolina Rose	B
Evangeline	C	Covington	BC
Beauregard	D	Beauregard	C

NOTE: Varieties with the same letter are not significantly different

Table 4.11 shows Duncan Groups ordered in descending form, meaning that those varieties in group A have a higher mean value than those in group D. An important outcome of this test is that most of the varieties, even though they have similar crop characteristics, their respiration rates were different enough to be classified as statistically different at 0.05 level. “Beauregard” was consistently across the two years the variety with the lowest respiration rate.

4.5 Discussion

Measuring respiration rates by measuring the consumption of substrate, which corresponds to the dry weight of the commodity, is a method that had been mentioned in the literature, (Salviet, 2004) However, there are no reports of this method having been carried on in previous research work.Thus the work presented in this thesis is an innovative and very useful technique in the measuring of respiration rates. Furthermore, the fact that the calculated values presented in Table 4.3 are in the same ranges that the values previously reported by other research cited in the introduction and Table 4.1supports the validity of this method. It also supports the assumption that one hundred percent of the dry weight loss by the sweetpotato is glucose. Explanation of the conversion of starch in glucose is given in the introduction section. Additionally the fact that sweetpotato roots are very low producers of ethylene, supports the assumption that the production of other volatiles is negligible.

The results in Table 4.3 and Duncan's Multiple Range Test in Table 4.11 show that the variety “Beauregard” is consistently the variety with the lowest respiration rate among tested varieties. “Carolina Rose” and “Hatteras” are consistently the ones with the higher respiration rates. The other two varieties “Evangeline”, and “Covington” vary in their results. “Covington” had low respiration rates at low temperature, but when temperature goes above 18.8˚C, its respiration rate increase very rapidly.

The respiration rate of the variety “Covington” stored under varying temperature is consistently higher than the sweetpotato roots of the same variety stored under stable conditions by the growers who participated in this study. The effect of temperature and variety were very important in the statistical result of the ANOVA test, as it is shown in Table 4.9, proving the theory that the two most important factors that contribute to the respiration rate are the genetic characteristics in first place, and the environment second.

4.6 Conclusions

Calculating respiration rates by measuring the substrate consumed in respiration as glucose is a valid and accurate method. This method is especially suitable for commodities that can be stored for long periods, such as sweetpotatoes.

“Beauregard” is the sweetpotato variety with the lowest respiration rate, from the tested varieties.“Carolina Rose” and “Hatteras” are consistently the ones with the higher respiration rates.

The other two varieties “Evangeline” and “Covington” vary in their results, with the remark that “Covington” had low respiration rate at low temperature, but when temperature goes above 18.8˚C its respiration rate increase very rapidly.

In order to reach the lowest possible respiration rate by a determined sweetpotato variety, it is necessary to avoid fluctuations in environmental conditions.

Ttemperature is the environmental condition that has the greatest impact on respiration rates.

Environmental conditions are a determining factor in the respiration rate of sweetpotatoes, but the genetic characteristics are the most important contributing aspect in the respiration rate of sweetpotato roots.

Breeders and growers can use the method presented in the present study to measure respiration rate of sweetpotatoes or other commodities, in order to make better variety selection.

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APPENDICES

APPENDIX A

Bending beam load cells, TEDEA RL1042, Specifications sheet.

RICE LAKE WEIGHING SYSTEMS

MODEL RL1042 SERIAL NUMBER **11401807**

RoHS

RATED CAPACITY	30 KG	OUTPUT AT RATED CAP.(R.O)	2.0181 MV/V
ACCURACY CLASS	I	TOTAL ERROR	<0.0200 %R.O.
ZERO BALANCE	: 0.0156 MV/V	ACCORDING TO H44	
30 MIN.ZERO RETURN/CREEP	< 0.0330 %R.O.	INSULATION RESIST	>2 GOhms
TEMPERATURE EFFECT ON		INPUT IMPEDANCE	: 415+/-15 Ohms
ZERO	< 0.0230 %R.O./DEG.C	OUTPUT IMPEDANCE	: 350+/-3 Ohms
SPAN	< 0.0100 %LOAD/DEG.C	TEST EXCITATION	10V dc

QA APPROVED

COLOR CODE

GREEN	+INPUT	BLACK	-INPUT
BLUE	+SENSE	BROWN	-SENSE
RED	+OUTPUT	WHITE	-OUTPUT

NTEP INFORMATION

CLASS	III 5-S
Nmax SINGLE	= 5000
Vmin	: 0.0030 kg
MINIMUM DEAD LOAD	: 0 kg
MAXIMUM CAPACITY	: 30 KG
SAFE LOAD LIMIT	: 45 KG
COMPENSATED TEMP	: -10 TO +40 C
NTEP CERTIFICATE	97-138

QA APPROVED

DATE 07/28/09

APPENDIX B

Single ended shear beam load cells, RF model: SBS-5KSE, Specifications sheet.

Transcell Technology inc.

975 DEERFIELD PKWY, BUFFALO GROVE, IL. 60089

TEL (847) 419-9180 FAX (847) 419-1515

1

LOAD CELL DATA SUMMARY

DATE : 8–16—2010

MODEL :	SBS-5KSE
SERIAL NUMBER :	7H921501012997
CAPACITY :	5000 lb
RATED OUTPUT :	2.99960 mV/V
CLASSIFICATION :	Class III Multiple
NTEP CC number:	95-146
Nmax:	5000

EXCITATION :	10 V DC/AC
THERMAL ZERO COEFF :	< 0.15 % F.S./100°F
THERMAL SENSE COEFF :	< 0.08 % F.S./100°F
INSULATION RESISTANCE :	> 5K MegOhms
SAFE OVERLOAD :	150 % F.S.
Minimum Dead Load:	0 kg
Vmin:	0.7 lb

ZERO BALANCE (mV/V)	NON-LINEARITY (%F.S.)	HYSTER-ESIS (%F.S.)	INPUT IMPEDANCE (ohms)	OUTPUT IMPEDANCE (ohms)
0.00060	< 0.020	< 0.020	389.00	350.00

CONNECT FOR COMPRESSION

+EXC : RED +SIG : GREEN

-EXC : BLACK -SIG : WHITE

INSPECTED BY : Vivian

QC 063 PASS

APPENDIX C

SAS output for the Statistical Analysis of Weight Loss percentage of five Sweetpotato Cultivars stored under Varying Temperature Conditions during the 2010 Storage season.

The GLM Procedure

Dependent Variable: y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	303	64223.3694	211.9583	25.13	<.0001
Error	4694	39584.9727	8.4331		
Corrected Total	4997	103808.3421			

R-Square	Coeff Var	Root MSE	y Mean
0.618673	-36.15841	2.903980	-8.031273

Source	DF	Type I SS	Mean Square	F Value	Pr > F
var	4	27779.62374	6944.90593	823.53	<.0001
temp	49	31481.60860	642.48181	76.19	<.0001
rep	1	2539.95675	2539.95675	301.19	<.0001
rep*var*temp	249	2422.18034	9.72763	1.15	0.0533

Source	DF	Type III SS	Mean Square	F Value	Pr > F
var	4	3909.657536	977.414384	115.90	<.0001
temp	49	7403.224903	151.086223	17.92	<.0001
rep	1	913.155375	913.155375	108.28	<.0001
rep*var*temp	249	2422.180341	9.727632	1.15	0.0533

The GLM Procedure

Tukey's Studentized Range (HSD) Test for y

NOTE: This test controls the Type I experimentwise error rate.

Alpha	**0.05**
Error Degrees of Freedom	4694
Error Mean Square	8.4331
Critical Value of Studentized Range	3.85916

Comparisons significant at the 0.05 level are indicated by *.**

var Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
Covingto - Beaurega	0.0875	-0.2655	0.4405	
Covingto - Evangeli	0.7365	0.3835	1.0894	***
Covingto - Hatteras	2.5326	2.2058	2.8594	***
Covingto - Carolina	6.5379	6.1849	6.8909	***
Beaurega - Covingto	-0.0875	-0.4405	0.2655	
Beaurega - Evangeli	0.6490	0.2716	1.0263	***
Beaurega - Hatteras	2.4451	2.0921	2.7981	***
Beaurega - Carolina	6.4505	6.0731	6.8278	***
Evangeli - Covingto	-0.7365	-1.0894	-0.3835	***
Evangeli - Beaurega	-0.6490	-1.0263	-0.2716	***
Evangeli - Hatteras	1.7961	1.4431	2.1491	***
Evangeli - Carolina	5.8015	5.4241	6.1788	***
Hatteras - Covingto	-2.5326	-2.8594	-2.2058	***
Hatteras - Beaurega	-2.4451	-2.7981	-2.0921	***
Hatteras - Evangeli	-1.7961	-2.1491	-1.4431	***
Hatteras - Carolina	4.0054	3.6524	4.3583	***
Carolina - Covingto	-6.5379	-6.8909	-6.1849	***
Carolina - Beaurega	-6.4505	-6.8278	-6.0731	***
Carolina - Evangeli	-5.8015	-6.1788	-5.4241	***
Carolina - Hatteras	-4.0054	-4.3583	-3.6524	***

The GLM Procedure

Duncan's Multiple Range Test for y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	**0.05**
Error Degrees of Freedom	4694
Error Mean Square	8.4331
Harmonic Mean of Cell Sizes	980

NOTE: Cell sizes are not equal.

Number of Means	2	3	4	5
Critical Range	.2572	.2708	.2799	.2866

Means with the same letter are not significantly different.

Duncan Grouping	**Mean**	**N**	**var**
A	-6.1362	1176	Covingto
A			
A	-6.2237	882	Beaurega
B	-6.8727	882	Evangeli
C	-8.6688	1176	Hatteras
D	-12.6741	882	Carolina

APPENDIX D

SAS output for the Statistical Analysis of Weight Loss percentage of five Sweetpotato Cultivars stored under Varying Temperature Conditions during the 2011 Storage season.

The SAS System 12:19 Thursday, April 12, 2012 7357

The GLM Procedure

Dependent Variable: y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	212	8619.31438	40.65714	9.47	<.0001
Error	3102	13323.79900	4.29523		
Corrected Total	3314	21943.11338			

R-Square	Coeff Var	Root MSE	y Mean
0.392803	-40.40578	2.072493	-5.129201

Source	DF	Type I SS	Mean Square	F Value	Pr > F
var	3	2629.442581	876.480860	204.06	<.0001
temp	41	5514.428097	134.498246	31.31	<.0001
rep	1	103.294251	103.294251	24.05	<.0001
rep*var*temp	167	372.149451	2.228440	0.52	1.0000

Source	DF	Type III SS	Mean Square	F Value	Pr > F
var	3	1100.859826	366.953275	85.43	<.0001
temp	41	1123.568034	27.404098	6.38	<.0001
rep	1	13.820075	13.820075	3.22	0.0730
rep*var*temp	167	372.149451	2.228440	0.52	1.0000

The GLM Procedure

Tukey's Studentized Range (HSD) Test for y

NOTE: This test controls the Type I experimentwise error rate.

Alpha	**0.05**
Error Degrees of Freedom	3102
Error Mean Square	4.295229
Critical Value of Studentized Range	3.63513

Comparisons significant at the 0.05 level are indicated by *.**

var Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
Beaurega - Covingto	0.75245	0.51656	0.98834	***
Beaurega - Carolina	1.27049	0.98158	1.55940	***
Beaurega - Hatteras	2.40526	2.15047	2.66005	***
Covingto - Beaurega	-0.75245	-0.98834	-0.51656	***
Covingto - Carolina	0.51804	0.22913	0.80695	***
Covingto - Hatteras	1.65281	1.39802	1.90760	***
Carolina - Beaurega	-1.27049	-1.55940	-0.98158	***
Carolina - Covingto	-0.51804	-0.80695	-0.22913	***
Carolina - Hatteras	1.13477	0.83024	1.43931	***
Hatteras - Beaurega	-2.40526	-2.66005	-2.15047	***
Hatteras - Covingto	-1.65281	-1.90760	-1.39802	***
Hatteras - Carolina	-1.13477	-1.43931	-0.83024	***

The GLM Procedure

Duncan's Multiple Range Test for y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	**0.05**
Error Degrees of Freedom	3102
Error Mean Square	4.295229
Harmonic Mean of Cell Sizes	765

NOTE: Cell sizes are not equal.

Number of Means	2	3	4
Critical Range	.2078	.2188	.2261

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	var
A	-4.1472	1020	Beaurega
B	-4.8996	1020	Covingto
C	-5.4176	510	Carolina
D	-6.5524	765	Hatteras

APPENDIX E

SAS output for the Statistical Analysis of Weight Loss percentage of the Sweetpotato Covington Variety stored in Commercial Facilities and under Varying Temperature Conditions during the 2010 Storage season.

The SAS System 12:19 Thursday, April 12, 2012 7269

The GLM Procedure

Dependent Variable: y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	83	7579.07542	91.31416	19.58	<.0001
Error	1318	6147.84479	4.66453		
Corrected Total	1401	13726.92021			

R-Square	Coeff Var	Root MSE	y Mean
0.552132	-37.63185	2.159751	-5.739158

Source	DF	Type I SS	Mean Square	F Value	Pr > F
var	1	1150.198016	1150.198016	246.58	<.0001
temp	55	4501.857255	81.851950	17.55	<.0001
rep	1	1295.134721	1295.134721	277.66	<.0001
var*temp	26	631.885426	24.303286	5.21	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
var	1	467.054159	467.054159	100.13	<.0001
temp	55	1595.580469	29.010554	6.22	<.0001
rep	1	1295.134721	1295.134721	277.66	<.0001
var*temp	26	631.885426	24.303286	5.21	<.0001

The GLM Procedure

Tukey's Studentized Range (HSD) Test for y

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	**0.05**
Error Degrees of Freedom	1318
Error Mean Square	4.664526
Critical Value of Studentized Range	2.77436
Minimum Significant Difference	0.3077
Harmonic Mean of Cell Sizes	379.1384

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	var
A	-3.6730	226	TullHill
B	-6.1362	1176	Covingto

The GLM Procedure

Duncan's Multiple Range Test for y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	**0.05**
Error Degrees of Freedom	1318
Error Mean Square	4.664526
Harmonic Mean of Cell Sizes	379.1384

NOTE: Cell sizes are not equal.

Number of Means	2
Critical Range	.3077

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	var
A	-3.6730	226	TullHill
B	-6.1362	1176	Covingto

APPENDIX F

SAS output for the Statistical Analysis of Weight Loss percentage of the Sweetpotato Covington Variety stored in Commercial Facilities and under Varying Temperature Conditions during the 2011 Storage season.

The SAS System 14:57 Wednesday, April 18, 2012 462

The GLM Procedure

Dependent Variable: y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	234	5645.875951	24.127675	10.63	<.0001
Error	1883	4273.927302	2.269744		
Corrected Total	2117	9919.803253			

R-Square	Coeff Var	Root MSE	y Mean
0.569152	-38.50360	1.506567	-3.912795

Source	DF	Type I SS	Mean Square	F Value	Pr > F
var	5	2963.096870	592.619374	261.10	<.0001
temp	93	2095.929807	22.536880	9.93	<.0001
rep	1	0.292149	0.292149	0.13	0.7198
var*temp	135	586.557125	4.344868	1.91	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
var	5	301.207551	60.241510	26.54	<.0001
temp	93	1275.793957	13.718215	6.04	<.0001
rep	1	0.292149	0.292149	0.13	0.7198
var*temp	135	586.557125	4.344868	1.91	<.0001

The GLM Procedure

Tukey's Studentized Range (HSD) Test for y

NOTE: This test controls the Type I experimentwise error rate.

Alpha	**0.05**
Error Degrees of Freedom	1883
Error Mean Square	2.269744
Critical Value of Studentized Range	4.03425

Comparisons significant at the 0.05 level are indicated by *.**

var Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
Rose - Warren	0.09902	-0.32916	0.52720	
Rose - Vick	0.70168	0.28947	1.11389	***
Rose - Barness	1.35636	0.92195	1.79077	***
Rose - TullHill	2.53128	2.13267	2.92990	***
Rose - Covingto	2.93163	2.60133	3.26192	***
Warren - Rose	-0.09902	-0.52720	0.32916	
Warren - Vick	0.60266	0.18879	1.01652	***
Warren - Barns	1.25734	0.82136	1.69332	***
Warren - TullHill	2.43226	2.03194	2.83259	***
Warren - Covingto	2.83261	2.50025	3.16496	***
Vick - Rose	-0.70168	-1.11389	-0.28947	***
Vick - Warren	-0.60266	-1.01652	-0.18879	***
Vick - Barns	0.65468	0.23437	1.07499	***
Vick - TullHill	1.82961	1.44641	2.21280	***
Vick - Covingto	2.22995	1.91844	2.54146	***
Barnes - Rose	-1.35636	-1.79077	-0.92195	***
Barnes - Warren	-1.25734	-1.69332	-0.82136	***
Barnes - Vick	-0.65468	-1.07499	-0.23437	***
Barnes - TullHill	1.17493	0.76795	1.58190	***
Barnes - Covingto	1.57527	1.23492	1.91561	***
TullHill - Rose	-2.53128	-2.92990	-2.13267	***
TullHill - Warren	-2.43226	-2.83259	-2.03194	***
TullHill - Vick	-1.82961	-2.21280	-1.44641	***
TullHill - Barness	-1.17493	-1.58190	-0.76795	***
TullHill - Covingto	0.40034	0.10706	0.69362	***
Covingto - Rose	-2.93163	-3.26192	-2.60133	***
Covingto - Warren	-2.83261	-3.16496	-2.50025	***
Covingto - Vick	-2.22995	-2.54146	-1.91844	***
Covingto - Barness	-1.57527	-1.91561	-1.23492	***
Covingto - TullHill	-0.40034	-0.69362	-0.10706	***

The GLM Procedure

Duncan's Multiple Range Test for y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	**0.05**
Error Degrees of Freedom	1883
Error Mean Square	2.269744
Harmonic Mean of Cell Sizes	248.4731

NOTE: Cell sizes are not equal.

Number of Means	2	3	4	5	6
Critical Range	.2651	.2791	.2885	.2954	.3009

Means with the same letter are not significantly different.

Duncan Grouping	**Mean**	**N**	**var**
A	-1.9680	203	Rose
A			
A	-2.0670	200	Warren
B	-2.6697	234	Vick
C	-3.3243	189	Barness
D	-4.4993	272	TullHill
E	-4.8996	1020	Covingto

APPENDIX G

SAS output for the Statistical Analysis of Respiration Rate of five Sweetpotato Cultivars stored under Varying Temperature Conditions during the 2010 Storage season.

Dependent Variable: y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	885	114325.2592	129.1811	3.94	<.0001
Error	4112	134917.3089	32.8106		
Corrected Total	4997	249242.5681			

R-Square	Coeff Var	Root MSE	y Mean
0.458691	90.18714	5.728056	6.351301

Source	DF	Type I SS	Mean Square	F Value	Pr > F
var	4	5760.87036	1440.21759	43.89	<.0001
temp	176	58600.55016	332.95767	10.15	<.0001
rep	1	405.10354	405.10354	12.35	0.0004
var*temp	704	49558.73514	70.39593	2.15	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
var	4	6851.18863	1712.79716	52.20	<.0001
temp	176	54638.75860	310.44749	9.46	<.0001
rep	1	405.10354	405.10354	12.35	0.0004
var*temp	704	49558.73514	70.39593	2.15	<.0001

The GLM Procedure

Tukey's Studentized Range (HSD) Test for y

NOTE: This test controls the Type I experimentwise error rate.

Alpha	**0.05**
Error Degrees of Freedom	4112
Error Mean Square	32.81063
Critical Value of Studentized Range	3.85937

Comparisons significant at the 0.05 level are indicated by *.**

var Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
Carolina - Covingto	0.4152	-0.2811	1.1115	
Carolina - Hatteras	0.8096	0.1133	1.5059	***
Carolina - Evangeli	1.6416	0.8972	2.3859	***
Carolina - Beaurega	3.1733	2.4290	3.9177	***
Covingto - Carolina	-0.4152	-1.1115	0.2811	
Covingto - Hatteras	0.3944	-0.2502	1.0390	
Covingto - Evangeli	1.2264	0.5301	1.9226	***
Covingto - Beaurega	2.7581	2.0618	3.4544	***
Hatteras - Carolina	-0.8096	-1.5059	-0.1133	***
Hatteras - Covingto	-0.3944	-1.0390	0.2502	
Hatteras - Evangeli	0.8320	0.1357	1.5283	***
Hatteras - Beaurega	2.3637	1.6674	3.0600	***
Evangeli - Carolina	-1.6416	-2.3859	-0.8972	***
Evangeli - Covingto	-1.2264	-1.9226	-0.5301	***
Evangeli - Hatteras	-0.8320	-1.5283	-0.1357	***
Evangeli - Beaurega	1.5318	0.7874	2.2762	***
Beaurega - Carolina	-3.1733	-3.9177	-2.4290	***
Beaurega - Covingto	-2.7581	-3.4544	-2.0618	***
Beaurega - Hatteras	-2.3637	-3.0600	-1.6674	***
Beaurega - Evangeli	-1.5318	-2.2762	-0.7874	***

The GLM Procedure

Duncan's Multiple Range Test for y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	**0.05**
Error Degrees of Freedom	4112
Error Mean Square	32.81063
Harmonic Mean of Cell Sizes	980

NOTE: Cell sizes are not equal.

Number of Means	2	3	4	5
Critical Range	.5073	.5342	.5521	.5654

Means with the same letter are not significantly different.

Duncan Grouping		**Mean**	**N**	**var**
	A	7.4892	882	Carolina
	A			
B	A	7.0740	1176	Covingto
B				
B		6.6796	1176	Hatteras
	C	5.8476	882	Evangeli
	D	4.3158	882	Beaurega

APPENDIX H

SAS output for the Statistical Analysis of Respiration Rate of five Sweetpotato Cultivars stored under Varying Temperature Conditions during the 2011 Storage season.

The GLM Procedure

Dependent Variable: y

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	752	63005.1137	83.7834	1.96	<.0001
Error	2976	127430.4411	42.8194		
Corrected Total	3728	190435.5548			

R-Square	Coeff Var	Root MSE	y Mean
0.330847	93.78497	6.543651	6.977291

Source	DF	Type I SS	Mean Square	F Value	Pr > F
var	4	1353.08811	338.27203	7.90	<.0001
temp	154	36360.04264	236.10417	5.51	<.0001
rep	1	143.15066	143.15066	3.34	0.0676
var*temp	593	25148.83230	42.40950	0.99	0.5544

Source	DF	Type III SS	Mean Square	F Value	Pr > F
var	4	1229.80175	307.45044	7.18	<.0001
temp	154	33830.18781	219.67654	5.13	<.0001
rep	1	143.15066	143.15066	3.34	0.0676
var*temp	593	25148.83230	42.40950	0.99	0.5544

The GLM Procedure

Tukey's Studentized Range (HSD) Test for y

NOTE: This test controls the Type I experimentwise error rate.

Alpha	**0.05**
Error Degrees of Freedom	2976
Error Mean Square	42.81937
Critical Value of Studentized Range	3.86002

Comparisons significant at the 0.05 level are indicated by *.**

var Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
Evangeli - Hatteras	1.3324	0.2426	2.4221	***
Evangeli - Carolina	1.3701	0.1886	2.5517	***
Evangeli - Covingto	1.4844	0.4436	2.5252	***
Evangeli - Beaurega	2.1271	1.0863	3.1679	***
Hatteras - Evangeli	-1.3324	-2.4221	-0.2426	***
Hatteras - Carolina	0.0378	-0.9833	1.0588	
Hatteras - Covingto	0.1520	-0.7022	1.0063	
Hatteras - Beaurega	0.7947	-0.0595	1.6490	
Carolina - Evangeli	-1.3701	-2.5517	-0.1886	***
Carolina - Hatteras	-0.0378	-1.0588	0.9833	
Carolina - Covingto	0.1143	-0.8543	1.0829	
Carolina - Beaurega	0.7570	-0.2117	1.7256	
Covingto - Evangeli	-1.4844	-2.5252	-0.4436	***
Covingto - Hatteras	-0.1520	-1.0063	0.7022	
Covingto - Carolina	-0.1143	-1.0829	0.8543	
Covingto - Beaurega	0.6427	-0.1482	1.4336	
Beaurega - Evangeli	-2.1271	-3.1679	-1.0863	***
Beaurega - Hatteras	-0.7947	-1.6490	0.0595	
Beaurega - Carolina	-0.7570	-1.7256	0.2117	
Beaurega - Covingto	-0.6427	-1.4336	0.1482	

The GLM Procedure

Duncan's Multiple Range Test for y

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	2976
Error Mean Square	42.81937
Harmonic Mean of Cell Sizes	654.0892

NOTE: Cell sizes are not equal.

Number of Means	2	3	4	5
Critical Range	.7095	.7470	.7721	.7907

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	var
	A	8.4259	414	Evangeli
	B	7.0935	765	Hatteras
	B			
	B	7.0557	510	Carolina
	B			
C	B	6.9415	1020	Covingto
C				
C		6.2988	1020	Beaurega