ABSTRACT

GARZON, JOSE GUALBERTO. Analysis by Applying Near-Infrared-Refractography and Statistical Modeling of Sweetpotato Weight Loss, Density and Quality Change Due to Long-Term Storage, Temperature and Water Stress. (Under the direction of Michael Boyette, PhD., PE).

'Beauregard', 'Covington', 'Evangeline', 'Hatteras' and 'Carolina Rose' sweetpotato (Ipomoea batatas (L) Lam) roots graded U.S. No. 1 were stored in environmentally controlled rooms for 300 days. All the sweetpotato roots used in this study were grown and stored in eastern North Carolina. The effect of relative humidity on root weight loss was experimentally tested by holding temperature constant at 14.1˚C ±0.1˚C, and sequentially changing relative humidity (RH) from 85%, to 75% and 65%. Each RH level was held constant for a period of 30 days; which required, a cycle of 90 days to complete one set of treatments. A total of three cycles and an additional period at 85% RH were necessary to complete 300 days of storage. Inside a second room variable temperature conditions were performed, with each temperature cycle lasting 90. Cycles were divided into five periods of 15 days each. At each period temperature was held at constant in the following order: 14.4˚C, 17˚C, 14.4˚C, 19˚C, 14.4˚C. Simultaneously, 'Covington' sweetpotatoes were stored in commercial storage rooms, with the temperature and relative humidity held constant at 14.4°C ±1˚C and 85% ± 5%, respectively, for the duration of all tests. Temperature, relative humidity and weight of sweetpotatoes were measured every hour for the entire duration of the study by a data acquisition system designed and

built for this specific application. Measuring density during long-term storage of 'Covington' sweetpotato under both variable temperature, and stable commercial storage conditions, was used to characterize the density change over time and varying environmental conditions. Density was also measured on 'Beauregard', 'Carolina Rose', 'Evangeline', and 'Hatteras' sweetpotatoes varieties stored under variable temperature conditions. In addition to density, other parameters such as dry matter, glucose, sucrose, fructose, maltose, Brix degrees, starch, beta-carotene, phenolic, vitamin C and fat in chips after fry-test were analyzed. The nutritional values during the first year were measured by chemical analysis and high pressure liquid chromatography (HPLC) and during the second year by near infrared spectroscopy (NIR) with a prediction curve based on the first year results. Density was measured by simple weight and volume displacement. Advanced statistical modeling was applied to develop mixed effects statistical models to predict weight loss of the five different varieties of sweetpotatoes during long-term storage as a result of temperature and water stresses. The models were developed using the Statistical Analysis System, SAS, version 9.3 for Windows. Linear mixed models were fit using the MIXED procedure.

Relative humidity treatments and variety significantly ($P<0.05$) affected weight loss of sweetpotatoes. Weight loss rates were lower at high RH because of low vapor pressure deficit (VPD), and increased as RH decreased and VPD increased. 'Beauregard' and 'Covington' had the lowest weight loss rate at any RH treatment when compared to 'Evangeline', 'Hatteras' and 'Carolina Rose'. Different levels of

environmental RH during long-term storage of sweetpotatoes effected weight loss at different rates; moreover, data showed that industry standard storage conditions of 14˚C/85%RH could be improved by increasing RH to 90%. Under variable temperature storage conditions, ‘Covington’ and ‘Beauregard’ experience the lowest rates of weight loss relative to the others. ‘Carolina Rose’ and ‘Hatteras’ experience the greatest rates of weight loss. The storage conditions significantly ($p<0.05$) affected the ‘Covington’ variety density and all nutritional characteristics analyzed in this study. The reduction in density over time in ‘Covington’ sweetpotatoes constitutes a benchmark standard to assess the storage length and conditions. Consequently, density better serves to describe the change in starch content and fat percentage in fried chips for sweetpotatoes; although, sugars, starch, beta-carotene, phenolic and vitamin C content could also be correlated to density. In the statistical modeling analysis, temperature, RH and variety had significant ($P<0.05$) effects on estimated values. Statistical models that predict sweetpotato weight loss during long-term storage based on environmental conditions could be used to forecast shrinkage of roots and plan business decisions as well as supply requirements from field production or packing houses.

Analysis by Applying Near-Infrared-Refractography and Statistical Modeling of Sweetpotato Weight Loss, Density and Quality Change Due to Long-Term Storage, Temperature and Water Stress

by
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A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Biological and Agricultural Engineering

Raleigh, North Carolina

2013

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DEDICATION

To

My wife Yvette

And

My daughter Fiorella Sophia

BIOGRAPHY

Jose Gualberto Garzon Banderas was born on June 29th, 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 volunteered as a VISTA (Volunteer in Service To America) for the AmeriCorps. This one year commitment took place in Sampson County, 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 and food safety 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 got the degree of Master in Science in Biological and Agricultural Engineering at NCSU in August, 2012.

Jose Garzon is married to Yvette Maria; they have been blessed with a daughter, Fiorella Sophia, who is 17 months old.

AKNOWLEDGEMENTS

I would like to thank my advisor Dr. Michael Boyette PhD, PE for his continuous support to my work, and for all the opportunities and resources that he has entrusted to me throughout my graduate studies, I deeply value that trust and consideration.

I would also like to express my gratitude to Dr. Christopher Gunter for his unconditional support, and his friendship.

I also would like to thanks Dr. Silvia Blankenship, Dr. Tarek Echekki and Dr. Grant Ellington for being part of my committee, and for their support throughout my course and research work.

This study was possible also because of the contribution of the following professionals and institutions:

Mr. Phil Harris, BAE Electronics Technician

Sweetpotato Research Collaborators at NCSU

Staff at the Horticultural Research Station in Clinton, NC

Staff at the Lower Coastal Plain Tobacco Research Station in Kinston, NC

McCain Foods

Golden Leaf Foundation

Numerous NC sweetpotato growers for their cooperation

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LIST OF ABREVIATIONS AND SYMBOLS

A.C.	After Curing
ANOVA	Analysis of Variance
B.C.	Before Curing
CRB	Complete Randomized Block
DF	Degrees of Freedom
E	Voltage
GLM	General Linear Model
HPLC	High Performance Liquid Chromatography
NIR	Near-Infrared-Refractography
NMR	Nuclear Magnetic Resonance
PAD	Pulse Amperometric Detector
P_{sat}	Saturation pressure of the air-vapor mixture
P_v	Actual pressure of the water vapor
RH	Relative Humidity
RHtrt	Relative Humidity Treatment
SD	Standard Deviation
T	Temperature

t	Time
VPD	Vapor Pressure Deficit
V_s	Volume of a sweetpotato sample
W_s	Weight of a sweetpotato sample
ρ_a	Apparent density

CHAPTER 1

Effect of Environmental Relative Humidity on Five Varieties of Sweetpotato (*Ipomoea batatas (L) Lam*) During Long-term Storage.

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Abstract. Sweetpotato (*Ipomoea batatas* (L) Lam) root varieties 'Beauregard', 'Covington', 'Evangeline', 'Hatteras' and 'Carolina Rose', all grading U.S. No. 1, were stored in an environmentally controlled room for 300 days. The influence of relative humidity on weight loss of the roots was experimentally determined by maintaining a constant temperature of 14.1˚C ±0.1˚C, and sequentially changing the relative humidity (RH) from 85%, to 75% and 65%. Each RH level was maintained for a period of 30 days. A cycle of 90 days was therefore required to complete one set of treatments. A total of three cycles and an additional period at 85% RH were necessary to complete 300 days of storage. The relative humidity variability in the controlled environment room was ± 5%; The relative humidity treatments (RHtrt) where established as follows: >85%RH, 75%-85%RH, 65%-74.9%RH and <65%RH. The experiment was a complete randomized block (CRB), and was conducted during two different storage seasons. Temperature, relative humidity and weight of sweetpotatoes were measured every hour for the entire duration of the study by a data acquisition system designed and built for this specific application. Relative humidity and the variety significantly ($P<0.05$) affected the weight loss of the sweetpotatoes. Weight loss rates were lower at high RH because of low vapor pressure deficit (VPD), and increased as RH decreased and VPD increased. 'Beauregard' and 'Covington' had the lowest weight loss rate of any RH treatment when compared to 'Evangeline', 'Hatteras' and 'Carolina Rose'. Environmental RH is a determining factor in the success of long-term storage of sweetpotato roots. Different levels of environmental RH during long-term storage of sweetpotatoes

would affect their weight loss at different rates; Industry standard storing conditions of 14˚C/85%RH could be improved by shifting RH to 90% provided that no condensation occurred inside the storage facility.

1.1. Introduction

According to the U.S. Dept. of Agriculture (USDA), National Agricultural Statistics Service, the US production of sweetpotatoes has increased from 581,773 tons in 2002 to 1,203,727 tons in 2012, a 107% increase. Furthermore, according to the Food and Agriculture Organization of the United Nations, FAO, the sweetpotato is the seventh most important food crop in the world, with an annual production of 104 million tons (FAO 2013). The increased production has caused an increase in demand of storage capacity and more sophisticated postharvest storage practices. During long-term storage of sweetpotatoes, weight loss is a major concern (Blankenship and Boyette 2002) and consequently efforts to reduce weight loss are important to the efficiency and profitability of the industry.

The long-term storage of sweetpotato is primarily affected by temperature, relative humidity and the specific cultivar. Other conditions like O2 and CO2 concentrations may influence weight loss as well, but in minimum amounts under industry standard storage conditions. The benefits of controlled atmosphere storage (where levels of O2 and CO2 are controlled) in sweetpotatoes have not been shown

to compensate for the added costs (Afek and Kays 2004). Previous results have shown that the most important factor that dictates how sweetpotato reacts during long-term storage is their genotype; therefore when different cultivars of sweetpotatoes are exposed to environmental stresses they will lose weight at different rates (Zhang et al. 2002; Garzon 2012).

This experiment tests the interaction of five sweetpotato varieties at four levels of relative humidity over time while keeping temperature constant. The difference between environmental relative humidity and moisture of sweetpotato roots creates a gradient in the chemical potential of water between the two systems. This moisture gradient or differential induces a transfer from high concentration to low (evaporation) which results in weight loss in the sweetpotatoes. This can be measured by various methods in the form of the vapor pressure deficit (Afek and Kays 2002).

Previous studies have shown the different results that can be obtained during long-term storage of sweetpotato at different environmental relative humidity (RH) levels. Sweetpotato roots from the variety 'Beauregard' stored at 15˚C during 4 months lost 11% of their initial fresh weight, when the RH was 85%, and 2.4% when RH was 95% (Afek and Kays 2002). In a different study in India, when sweetpotato roots were stored in the open environment for 2 months, they lost 44% of their initial fresh weight. Simultaneously, sweetpotato roots stored in a clamp covered with sand, soil, or sawdust lost 30% of their initial weight (Ray et al. 1994). These two studies as

well as practical experience underline the importance of controlling the environment conditions, including relative humidity, during long-term storage.

In addition to a vapor pressure deficit, another factor that influences moisture loss from sweetpotato roots is the nature of its epidermis. After curing, sweetpotato roots will develop a new layer of suberized parenchyma cells (Walter Jr and Schadel 1983), which slows dehydration. During long-term storage, sweetpotatoes will experience a secondary growth of epidermal cells, which is called periderm (Kays 2004). The periderm will decrease water loss further in sweetpotatoes during long-term storage. This study will measure average weight losses after 100, 200 and 300 days.

The objective of this study is to measure weight loss of five sweetpotato varieties during long term storage due to environmental relative humidity. The sweetpotato varieties evaluated are ‘Beauregard’, ‘Carolina Rose’, ‘Covington’, ‘Evangeline’, and ‘Hatteras’.

1.2. Materials and Methods

This study was conducted in controlled environment storage rooms using five sweetpotato varieties. The selected varieties have similar characteristics described below, and are used primarily for fresh consumption. All the tested varieties have orange flesh with a dry matter content of 20% ± 2%. The sweetpotato varieties were ‘Beauregard’, ‘Carolina Rose’, ‘Covington’, ‘Evangeline’, and ‘Hatteras’. The sweetpotato roots were grown near Kinston, NC, at the Lower Coastal Plain Research Station following the standard growing practices utilized in eastern North Carolina. This experiment was replicated consecutively over a period of two years.

Immediately after harvesting, the roots were transported to the Horticultural Crops Research Station in Clinton, NC, where they were cured. The curing process was completed in temperature controlled rooms where roots were kept at 29.4°C ±2°C and 85% RH for 7 days according to the recommended procedure (Kader 2002; Blankenship and Boyette 2002). The primary goal of curing sweetpotatoes is to heal wounds caused by handling during the harvest and transportation process. Wound healing is achieved during curing by the development of a new layer of suberized parenchyma cells (Walter Jr and Schadel 1983). After curing the roots were taken to the controlled environment room on the campus of North Carolina State University at Raleigh, NC. Eighty kg per cultivar of sweetpotatoes meeting U.S. No. 1 grade standards were selected for the tests (United States Department of

Agriculture. Agricultural Marketing Service, Fruit and Vegetable Programs. Fresh Produce Branch 2005).

The roots were stored in a controlled environment room arranged as a complete randomized block (CRB) with each variety replicated four times. Each experimental repetition consisted of 20 kg of sweetpotato, contained in plastic lugs. The lugs were placed over bending beam load cell scales (TEDEA RL 1042, City of Industry, CA) with a maximum capacity of 30 kg each, where weight data was collected continuously every hour during the length of the study. Inside the room the five varieties of sweetpotato roots were submitted to the following storage treatments. The temperature was held constant at 14.1˚C ±0.1˚C with the relative humidity (RH) sequentially changed from 85%, to 75% and 65%, targeting each level for a period of 30 days; Therefore, a cycle of 90 days was needed to complete one set of treatments. A total of three cycles and an additional period at 85% RH were necessary to complete 300 days of storage. The relative humidity variability in the controlled environment room was ± 5%; Thus, relative humidity treatments (RHtrt) where measured as follows: >85%RH; 75%-85%RH; 65%-74.9%RH; and <65%RH. These treatments were chosen to represent the industry standard (>85%RH) and three reduced RH environments. The upper limit of the cycle was established because 85% is the industry recommended storage RH (Kader 2002). The lower limit was set at 65% in order to avoid very critical vapor pressure deficit (VPD) value, which would cause high water stress on the roots (Afek and Kays 2004). Desired humidity levels were maintained using a humidifier (Humidifier 707TW, Herrmidifier,

Sanford, NC) and a de-humidifier (Accudry Model AD65USM, Whirlpool, USA). This experiment was repeated two times. Temperature inside the rooms was maintained at 14˚C because that is the optimum recommended temperature for the storage of sweetpotatoes. (Kushman and Pope 1972; Kader 2002; Kays 2004; Boyette 2009). Environmental temperature, RH, and weight for each lug of roots were recorded hourly during the 300 days using data loggers (HOBO U12, Pocasset, MA.). RH was measured at 8 different points, located at 4 different heights inside the room; no significant difference was found between data logger readings.

Sweetpotatoes are alive and respire during storage and their weight loss is driven by respiration and evapotranspiration. Evapotranspiration is caused by the diffusion of water into the environment. The potential of this water diffusion can be measured by the vapor pressure deficit (VPD). VPD is proportional to the storage temperature and relative humidity and is the difference between the amount of moisture in the air and the amount of moisture when the air-vapor mixture is saturated, at a given temperature (Kays 2004). Sweetpotato roots are assumed to be near saturation, or 100 % relative humidity. Therefore, the force pulling water from the roots would be environmental temperature and relative humidity, which could be expressed by the VPD. Thus, air-vapor mixture saturation pressure (P_{sat}), at the temperature of the mixture, minus the actual pressure of the water vapor (P_v), would result in the VPD, expressed in equation 1.1.

$$VPD = P_{sat} - P_v \quad (1.1)$$

P_{sat} is a non-linear function of temperature. In the air-vapor mixture, the saturated pressure is given by the water vapor pressure for which the vapor and liquid form of water would be in equilibrium; P_{sat} is very slightly affected by the total pressure of the atmosphere (Henderson et al. 1997), so it may be obtained from steam tables. Or alternatively, it could be calculated with an empirical equation (eq. 1.2) for the temperature range from 273.16K to 533.16K (Keenan and Keyes 1936):

$$ln\left(\frac{P_{sat}}{R'}\right) = \frac{(A + BT + CT^2 + DT^3 + ET^4)}{(FT + GT^2)} \quad (1.2)$$

Where: T=temperature (K) R'=22,105,649.25; A=-27,405.526; B=97.5413; C=-0.146244; D=0.12558x10^{-3}; E=-0.48502x10^{-7}; F=4.34903; G=0.39381x10^{-2}

Applying equation 1.2, P_{sat} at 14.1˚C would be 1,639.4 Pa. The actual pressure of the water vapor (P_v) would depend on the RH. Relative humidity could be understood as the amount of water in the air-vapor mixture at a given temperature that is most often expressed as a percentage. However, the definition of this parameter is "the actual pressure of the water vapor (P_v) in the air-vapor mixture to the saturation pressure (P_{sat}) at the temperature of the mixture"(Henderson et al.

1997). The result is a fraction (equation 1.3), which could be multiplied by 100 in order to express it as a percentage.

$$RH = \frac{P_v}{P_{sat}} \quad (1.3)$$

Since, temperature would be kept constant; P_v would be determined by the RH of the storage room. After determining P_{sat} (eq. 1.2) and P_v (eq. 1.3), VPD could be calculated (eq. 1.1).

There was little to no decay in this study, and any decayed root was taken out of the plastic bins and the proportional weight of the root discounted. The proportional weight of the root was calculated by dividing the initial weight by the number of roots inside the each plastic bin.

Data analysis was conducted using the Statistical Analysis System version 9.3 for Windows (SAS Institute, Cary, NC). Analysis of variance (ANOVA) and mean comparison of weight loss by variety and storage conditions were done using Fisher's least significant difference (LSD) at $P<0.05$. A statistical model was created for the data collected from the five sweetpotato cultivars stored in environment controlled rooms, at variable relative humidity and constant temperature (14.1˚C ±0.1˚C) as it was described above. The lugs holding up to 30 kg of sweetpotato roots were arranged in a complete randomized design with four replications. The experiment was replicated for 2 storage seasons; each storage season corresponds to 300 days. At the beginning of each season fresh cured sweetpotato roots were

used and their mass measurements were aggregated daily for the analysis. Linear mixed models were fit using the GLIMMIX procedure of SAS (Cary, NC) statistical software package. The response variable used was weight at time *t*, relative to initial weights at the beginning of the observation period.

Figure 1.1: a) Sweetpotato roots stored in a controlled environment room on NCSU campus. b) Humidifier (707TW, Herrmidifier, Sanford, NC). c) Bending beam load cells strain sensors (TEDEA RL 1042, City of Industry, CA).

1.3. Results and Discussion

The hypothesis was that relative humidity would significantly ($p<0.05$) affect weight loss of the cured sweetpotato roots during long-term storage depending on cultivar and to a limited extent the relative humidity treatment (Table 1.1). ‘Covington’ lost the least amount of weight due to RH, followed by ‘Beauregard’, ‘Evangeline’, ‘Carolina Rose’ and ‘Hatteras’. Weight loss was differently influenced by RH at each RHtrt level. The two cultivars that showed less susceptibility to water stress ‘Covington’ and ‘Beauregard’ did not have statistically significant differences between RHtrt ranges; However, weight loss was successfully reduced at higher RH. The three varieties that lost the largest amount of weight due to RH, ‘Evangeline’, ‘Carolina Rose’ and ‘Hatteras’, showed significant differences in weight loss at the two higher RHtrt ranges compared with the results at the two lower RHtrt ranges. To improve the interpretability of the weight loss means in Table 1.1, the values were converted to percentage change.

Table 1.1: Mean weight loss percentage of different relative humidity treatments (RHtrt) during long-term storage of five sweetpotato varieties.

				Significant Difference*	
Variety	**RHtrt**	**Mean**	**Std. Error**	**RHtrt**	**Variety**
Beauregard	>85	-7.19%	0.15%	ab	b
	75-85	-6.40%	0.18%	a	
	65-74.9	-8.41%	0.13%	ab	
	<65	-9.67%	0.16%	bcd	
Carolina Rose	>85	-10.98%	0.25%	cd	d
	75-85	-8.53%	0.19%	ab	
	65-74.9	-12.09%	0.17%	e	
	<65	-15.22%	0.25%	f	
Covington	>85	-6.86%	0.14%	a	a
	75-85	-6.42%	0.16%	a	
	65-74.9	-7.90%	0.11%	ab	
	<65	-8.77%	0.14%	abc	
Evangeline	>85	-9.99%	0.24%	bcd	c
	75-85	-9.75%	0.25%	bcd	
	65-74.9	-12.35%	0.20%	e	
	<65	-13.76%	0.29%	e	
Hatteras	>85	-15.59%	0.34%	f	e
	75-85	-14.69%	0.36%	f	
	65-74.9	-18.45%	0.29%	g	
	<65	-20.84%	0.37%	h	

*Mean separation by Fisher's LSD at P≤0.05. Means with the same letter are not significantly different

The effects of variety, RHtrt, and storage length (daysold) obtained from the type III statistical analysis (Table 1.2) clearly shows the benefit of storing sweetpotatoes at a high RH. Furthermore, the significance of *F*-test indicates the importance of RH and variety during long-term storage of sweetpotatoes. Differences in weight loss across varieties were statistically significant as reflected by the *F*-test. When the

effect of the interaction between variety and RHtrt is analyzed, the effect of variety depends on RHtrt. The year effect was not statistically significant, as the data collected from the two years was similar. The duration of storage (daysold) was statistically significant, meaning that storage length had direct effect over weight loss.

Table 1.2: Type 3 test of fixed effects for relative weight loss of sweetpotatoes stored in a variable environmental RH and constant temperature.

Effect	Numerator DF	Denominator DF	F Value	Pr > F
year	1	26	1.83	0.1882
variety	4	26	18.39	<.0001
RHtrt	3	9,210	9.36	<.0001
Daysold	301	9,210	178.63	<.0001
Year*variety	4	26	2.34	0.0817
Variety*RHtrt	12	9,210	55.37	<.0001

To evaluate the effect of relative humidity during long-term storage at different periods, the response variable was converted to g/(kg Hr) and the mean value calculated at each RHtrt. The complete storage season was divided into three terms: storage term 1 from 1 to 100 days, storage term 2 from 101 to 200 days, and storage term 3 from 201 to 300 days, (Table 1.3). Vapor pressure deficit values were calculated for each relative humidity category. VPD values are lower when RH is higher, which results in a slower weight loss. The results obtained during the first

term were probably influenced by the faster initial weight loss, rather than by VPD; Therefore, they do not correlate to the environmental factors. Initial weight loss is faster due to higher starch reserves, thinner epidermis, and stress caused during harvest and curing. As it was mentioned earlier vapor pressure deficit is the force behind weight loss due to evapotranspiration; In Table 1.3 VPD values for each RHtrt range are shown. At a constant temperature of 14.1˚C and 85% RH, the VPD is 245 Pa; but when RH drops to 65%, the VPD increases to 574 Pa, more than double the value at the recommended RH. ‘Beauregard’ and ‘Covington’ show the least susceptibility to water stress. When weight loss becomes more stable during the second and third term, it is possible to see how VPD influenced a small increase in weight loss. ‘Evangeline’ roots show a very small increase on the rate of weight loss due to RHtrt during the second storage term, but at the third term the weight loss increased very rapidly from 0.009 to 0.030 g/(kg Hr). ‘Carolina Rose’ in the second term showed increased weight loss from 0.017 to 0.035 g/(kg Hr), at >85% and <65% RH respectively. Weight loss was also successfully reduced by higher relative humidity in ‘Carolina Rose’ during the third term, losing only 0.015 g/(kg Hr) at >85% RH compared to 0.031 g/(kg Hr) lost at <65% RH. The most susceptible sweetpotato variety to water stress during long-term storage was ‘Hatteras’. This variety showed higher weight loss rates even at high relative humidity at all the storage terms. ‘Hatteras’ weight loss at >85% RH during the second term was 0.027 g/(kg Hr) and during the third term it was 0.022 g/(kg Hr). When relative humidity

was <65%, ‘Hatteras’ weight loss was 0.037 g/(kg Hr) during the second term and during the third term it was 0.039 g/(kg Hr).

Table 1.3: Weight loss mean and standard error of five sweetpotato varieties at different environmental relative humidity (RHtrt) and different storage terms.

		Beauregard		
			Storage term	
		1	**2**	**3**
RHcat (%)	**VPD (Pa)**		**g/(kg Hr)**	
>85	**<245**	-0.024 ± 0.004	-0.017 ± 0.002	-0.013 ± 0.001
75-85	**410-245**	-0.037 ± 0.001	-0.022 ± 0.002	-0.023 ± 0.002
65-74.9	**574-411**	-0.030 ± 0.001	-0.024 ± 0.001	-0.019 ± 0.001
<65	**>574**	-0.031 ± 0.003	-0.016 ± 0.001	-0.022 ± 0.001
		Carolina Rose		
			Storage term	
		1	**2**	**3**
RHcat (%)	**VPD (Pa)**		**g/(kg Hr)**	
>85	**<245**	-0.052 ± 0.003	-0.017 ± 0.002	-0.015 ± 0.002
75-85	**410-245**	-0.047 ± 0.002	-0.021 ± 0.001	-0.013 ± 0.004
65-74.9	**574-411**	-0.042 ± 0.002	-0.030 ± 0.001	-0.026 ± 0.003
<65	**>574**	-0.035 ± 0.002	-0.035 ± 0.003	-0.031 ± 0.002
		Covington		
			Storage term	
		1	**2**	**3**
RHcat (%)	**VPD (Pa)**		**g/(kg Hr)**	
>85	**<245**	-0.034 ± 0.002	-0.012 ± 0.001	-0.012 ± 0.001
75-85	**410-245**	-0.030 ± 0.001	-0.014 ± 0.002	-0.012 ± 0.012
65-74.9	**574-411**	-0.021 ± 0.001	-0.015 ± 0.001	-0.014 ± 0.003
<65	**>574**	-0.019 ± 0.003	-0.014 ± 0.001	-0.013 ± 0.001
		Evangeline		
			Storage term	
		1	**2**	**3**
RHcat (%)	**VPD (Pa)**		**g/(kg Hr)**	
>85	**<245**	-0.043 ± 0.006	-0.026 ± 0.022	-0.009 ± 0.006
75-85	**410-245**	-0.041 ± 0.002	-0.030 ± 0.002	-0.033 ± 0.005
65-74.9	**574-411**	-0.038 ± 0.007	-0.028 ± 0.002	-0.025 ± 0.003
<65	**>574**	-0.038 ± 0.005	-0.024 ± 0.001	-0.030 ± 0.001
		Hatteras		
			Storage term	
		1	**2**	**3**
RHcat (%)	**VPD (Pa)**		**g/(kg Hr)**	
>85	**<245**	-0.075 ± 0.004	-0.027 ± 0.003	-0.022 ± 0.001
75-85	**410-245**	-0.075 ± 0.003	-0.044 ± 0.003	-0.038 ± 0.003
65-74.9	**574-411**	-0.058 ± 0.002	-0.045 ± 0.002	-0.038 ± 0.002
<65	**>574**	-0.054 ± 0.005	-0.037 ± 0.002	-0.039 ± 0.002

1.4. Conclusions

The influence of environmental relative humidity on sweetpotato root weight loss during long-term storage could be measured as the vapor pressure deficit. It is clear from this study that the effect of VPD varies among sweetpotato cultivars. It has been shown that maintaining relative humidity above 85% would successfully reduce the rate of weight loss in all the studied varieties. However, statistically different weight loss rates were obtained due to genotype. The 'Covington' cultivar lost the least amount of weight in the experiment, 'Beauregard' loss the second least amount of weight. The difference between the two best varieties and the other three was considerable, these varieties loss more weight during the study in the following order: 'Evangeline', 'Carolina Rose' and 'Hatteras'. Lower humidity resulted in higher VPD and greater weight loss in all the sweetpotato cultivars.

RH could be further increased as long as condensation is avoided. Free water on sweetpotato roots could cause disease problems; To avoid this condition RH and temperature combinations should always be above the dew point temperature (Hide and Lapwood 1992; Afek and Warshavsky 1998). Dew point conditions could be derived by simple observation in the psychrometric chart. The industry standard storing conditions at 14˚C/85%RH could be improved by shifting RH to 90%.

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CHAPTER 2

Changes in density and Phytonutrients in 'Covington' sweetpotatoes (*Ipomoea batatas (L) Lam*) and four other cultivars during long-term storage.

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Abstract. Measuring density during long-term storage of ‘Covington’ sweetpotato (Ipomoea batatas (L) Lam) under both variable temperature, and stable commercial storage conditions (14.4˚C ± 1˚C and 85% ± 5% RH) was used to characterize its density change over storage time and conditions. Density was measured on the varieties ‘Beauregard’, ‘Carolina Rose’, ‘Covington’, ‘Evangeline’, and ‘Hatteras’ sweetpotatoes, stored under variable temperature conditions. In addition to density, other parameters such as dry matter, glucose, sucrose, fructose, maltose, Brix degrees, starch, beta-carotene, phenolic, vitamin C and fat in chips by chemical analysis using HPLC and NIR were tested. All the sweetpotato roots used in this study were grown and stored in eastern North Carolina during the 2011 and 2012 crop years. Roots were U.S. No 1 grade. The ‘Covington’ roots that were stored under variable conditions were kept in an environmentally controlled room where the temperature was cycled. Each complete cycle lasted 90 days and was divided in five periods of 15 days. Each period was held at constant temperatures in the following order: 14.4˚C, 17˚C, 14.4˚C, 19˚C, 14.4˚C. The target temperature in commercial storage rooms was 14.4°C ±1˚C. Relative humidity was constant at 85% ± 5% for the duration of all tests. For the ten month duration of the tests, the temperature and relative humidity were measured and recorded every hour. The sweetpotato density and all the other traits were measured periodically during both years. The nutritional values during the first year were measured by chemical analysis and high pressure liquid chromatography (HPLC) and during the second year by near infrared spectroscopy (NIR) with a prediction curve based on the first year results. Density

was measured by simple weight and volume displacement. Density of ‘Covington’ was statistically significant ($p<0.05$) as affected by storage conditions. Variety had a significant effect ($p<0.05$) on density and all nutritional characteristics analyzed in this study. Covington’ lost 1% of its density during curing. After 10 months of storage, the control ‘Covington’ sweetpotatoes in the stable environment lost 8% of their initial density whereas treated ‘Covington’ sweetpotatoes in the varying environment lost 12% of their density. This could be explained by a more rapid use of energy reserves caused by the accelerated metabolic rates due to temperature stress. Both ‘Beauregard’ and ‘Carolina Rose’ lost 9% of their density over ten months of storage. Additionally, ‘Evangeline’ lost 11%, and ‘Hatteras’ lost 17% over the same period. The reduction in density over time in ‘Covington’ sweetpotatoes constitutes a benchmark standard to assess the length and conditions of storage for ‘Covington’ sweetpotatoes. Consequently, density better serves to describe the change in starch content and fat percentage in fried chips for sweetpotatoes; although, sugars, starch, beta-carotene, phenolic and vitamin C content could also be estimated from this study of density. This study demonstrates that measuring the density of sweetpotatoes during long-term storage can be a quick, simple and efficient method to evaluate and monitor the condition of sweetpotatoes and it can be correlated to nutritional values.

2.1. Introduction

'Covington' sweetpotato, *Ipomoea batatas* (L.) Lam, is North Carolina's most cultivated variety. Approximately, 65,000 acres of sweetpotatoes were grown in North Carolina in 2011(NCDA&CS 2011). The percentage of 'Covington' sweetpotatoes virus-indexed G1 and G2 plants produced in North Carolina was 78%, with 'Beauregard' 9%, 'Evangeline' 4%, and others 5% making up the remainder of the crop (NCCIA, The North Carolina Crop Improvement Association 2011), To market sweetpotatoes throughout the year, it is necessary to store the roots for 10 months or more. For this reason, it is necessary to select a characteristic that would allow producers and packers to quickly and simply assess the quality of sweetpotatoes during storage. This study characterizes how the quality of 'Covington' sweetpotatoes changes during storage by measuring their density and relating it to starch content and other less easily measured characteristics.

Sweetpotatoes continue to live and respire after harvest. The rate of respiration as measured in weight loss over a specified period of time (termed by growers and packers as "shrinkage") is an indication of their storage life. The shrinkage corresponds to the loss of volume due to substrate consumption for respiration of the sweetpotato (Kays 2004), and water loss from the sweetpotato to the environment due to evapotranspiration. These losses also cause a weight reduction in sweetpotatoes. However, the loss of weight is greater than the loss of volume, and as result the sweetpotato density decreases.

Density is a very important food material property. It is used in many food processes such as separation, centrifugation, sedimentation, transportation and to determine the power required for pumping are determined by the density of the food (Sahin and Sumnu 2006). “Density also plays a significant role in food texture and quality, since density, shrinkage and porosity are the most common structural properties”(Rahman 2009). Also density has been previously described as an important quality parameter of sweetpotato (Stewart et al. 2000; Kushman et al. 1966); therefore, using density as a quality parameter to determine the storage conditions and storage length of sweetpotatoes would be a valid tool for the postharvest assessment of this root. There are no known previous studies that have measured the changes in density during the postharvest handling of sweetpotatoes.

Although sweetpotatoes are harvested primarily from September through November, excellent quality sweetpotatoes are available from North Carolina throughout the year due to modern and sophisticated postharvest storage facilities. It is estimated that more than 95 percent of the US long-term sweetpotato storage capacity is located in North Carolina. Further, it was reported in the winter 2012 newsletter of the National Sweet Potato Council that it is possible that more US sweetpotatoes may presently be marketed for processing than as whole unprocessed roots. If this is the case, it is a turning point in the US sweetpotato industry.

By the nature of their industry, processors may have more exacting quality standards than those necessary for the unprocessed market. With a growing portion of North Carolina sweetpotatoes coming out of storage throughout the year destined for processing, it has become necessary to develop benchmarks and create tools to standardize and measure quality over a storage life that may last 10 months or more. There are a great many either chemical or physical tests that may yield valuable information about the condition of a sample of stored sweetpotatoes (Rahman 2009). Most of these require sophisticated laboratory equipment and are time consuming. An ideal test from the standpoint of both the grower/packers and the processors would be one that may be easily done on the farm. Quality control has always been an important aspect of the fresh produce industry but with the exacting demands of the processing industry, quality of the raw feed stock is paramount.

Public attention has been gradually shifting to consumption of more nutritious products. Sweetpotatoes have captured a lot of that attention due to their nutritional value. This root is high in pro-vitamin A beta-carotene (Woolfe 1992). It has been considered a low glycemic index food (Wolever et al. 1994), due to its composition of complex carbohydrates as starch. According to the NCDA&CS the production of sweetpotatoes has doubled in the last ten years, which reflects the increase in consumption of this vegetable.

2.1.1 Objectives

The first objective of this work has been to develop quick, simple and efficient methods to evaluate and monitor the condition of sweetpotatoes in storage and to verify and correlate changes in density with other important characteristics that do not lend themselves to quick and simple measurement techniques.

The second objective of this research has been to develop benchmark standards for ‘Covington’ sweetpotatoes that describe various characteristics and expected rates of change throughout the entire storage period and compare those standards with the results obtained from the other four commonly grown varieties.

This study would develop a reference chart of density over time for the five sweetpotato varieties under ideal storage conditions.. The chart time period corresponds to 10 months which is a reasonable limit of most storage. Along with density, laboratory analysis was conducted in order to determine levels of dry matter, starch content, carotenes, vitamin C, sugars, phenolic along with a fry test to determine oil retention. The goal was to correlate the density of the stored sweetpotato to their starch content, and to the laboratory results of the other characteristics of the roots that would be more difficult to analyze.

2.1.2 Overview of the Study

The data for this study was collected during two storage periods (2011 and 2012). Each storage period lasted 10 months. Storage conditions during each storage period were varied. The following cultivars were studied: ‘Covington’ ‘Beauregard’, ‘Carolina Rose’, ‘Evangeline’, and ‘Hatteras’.

During the 2011 storage period, ‘Covington’ sweetpotatoes were stored in two different conditions: 1.) Laboratory scale volume, under variable temperature, in an on-campus controlled environment room. 2.) Commercial scale volume, under constant temperature, inside commercial storage rooms at four different locations. The four other sweetpotato cultivars were stored under one set of conditions, which were a laboratory scale volume, under variable temperature, in an on-campus controlled environment room. Nutritional content of sweetpotato roots during this period was analyzed by wet chemistry and HPLC methods.

During the 2012 storage period, ‘Covington’ sweetpotatoes were stored in three different conditions: 1.) Laboratory scale volume, under variable temperature, in an on-campus controlled environment room. 2.) Semi-commercial scale volume, under variable temperature, in a controlled environment room located at the Horticultural Crops Research Station in Clinton, N.C. 3.) Commercial scale volume, under constant temperature, inside commercial storage rooms at four different locations. The four other sweetpotato cultivars were stored under one set of conditions, which were a laboratory scale volume, under variable temperature, in an on-campus

controlled environment room. Nutritional content of sweetpotato roots during this period was determined using NIR. All the variables are defined in the following section. Figure 2.1 shows a schematic representation of this study.

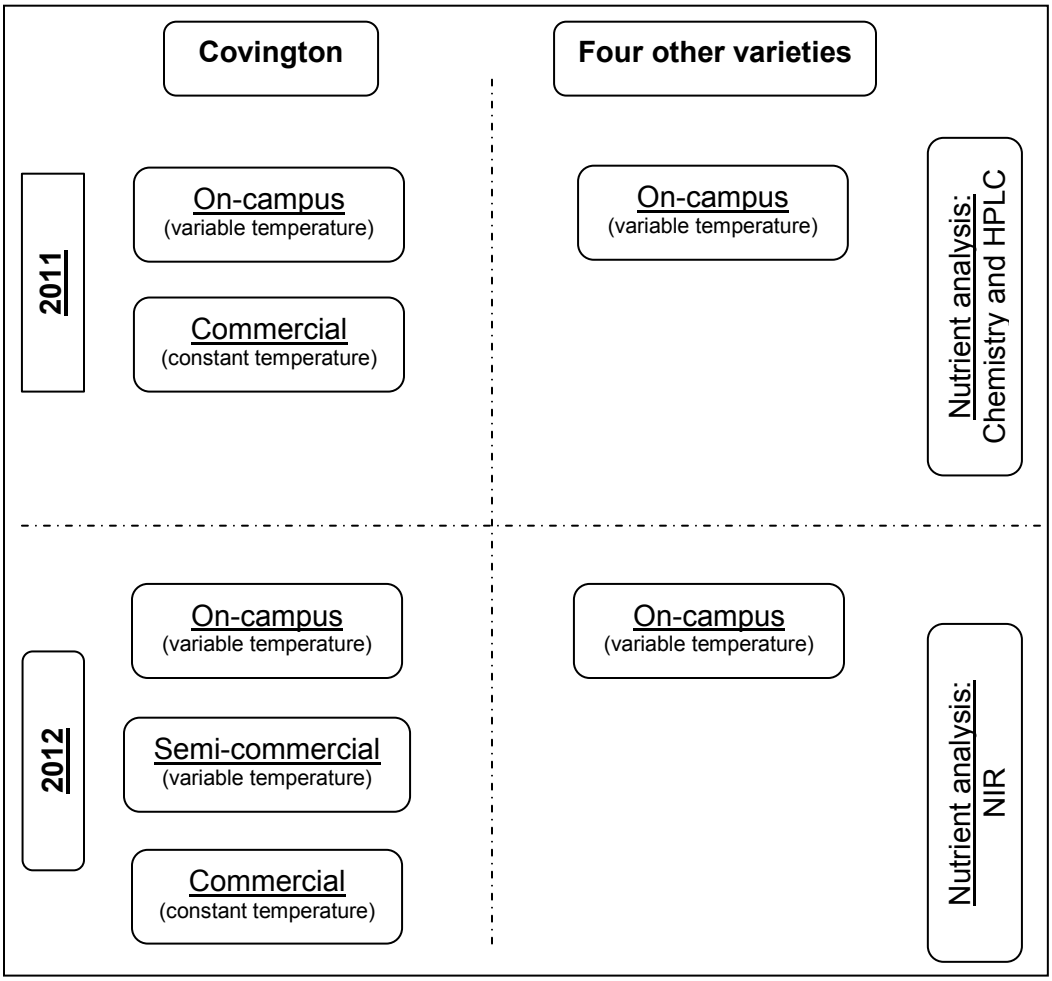

Figure 2.1: Schematic overview of the study.

2.2. Materials and Methods

All sweetpotatoes were grown in eastern North Carolina and were hand harvested in mid-October. All the roots were first cured at 29.4°C ±1˚C and 90% ±5% RH for 7 days. 'Covington' sweetpotatoes were subjected to two conditions: The first lot of 'Covington' roots was stored in controlled environment rooms on the campus of North Carolina State University in Raleigh, NC. The second lot was stored in controlled environment rooms at the Horticultural Crops Research Station in Clinton, NC. The desired temperature of both lots was changed in cycles from 14.4˚C to 21˚C while relative humidity (RH) remained constant at 85% ±5%. Each temperature cycle lasted 90 days and was divided in periods of 15 days. Each 15 days period had constant temperatures in the following order: 14.4˚C, 17˚C, 14.4˚C, 19˚C, 14.4˚C. This temperature cycle is shown in Figure 2.2. The lower limit of the cycle was selected because that is the optimum recommended temperature for the storage of sweetpotatoes (Kushman and Pope 1972). The upper limit was selected for the reason that above 19˚C sweetpotatoes would start sprouting after a few days of storage and this storage condition in modern facilities could not be tolerated.

After being held at a non-ideal temperature for 15 days, the temperature was lowered to the ideal ranges in order to mimic erratic and unacceptable storage conditions and to avoid sprouting. Roots stored on campus were in plastic boxes of up to 30kg each, and was considered a lab scale storage room. The storage room at the Research Station was stocked with 11,000 kg of sweetpotatoes in 450 kg

wooden bins which would be considered a semi-commercial storage room. Figure 2.3 shows the conditions in the rooms described above.

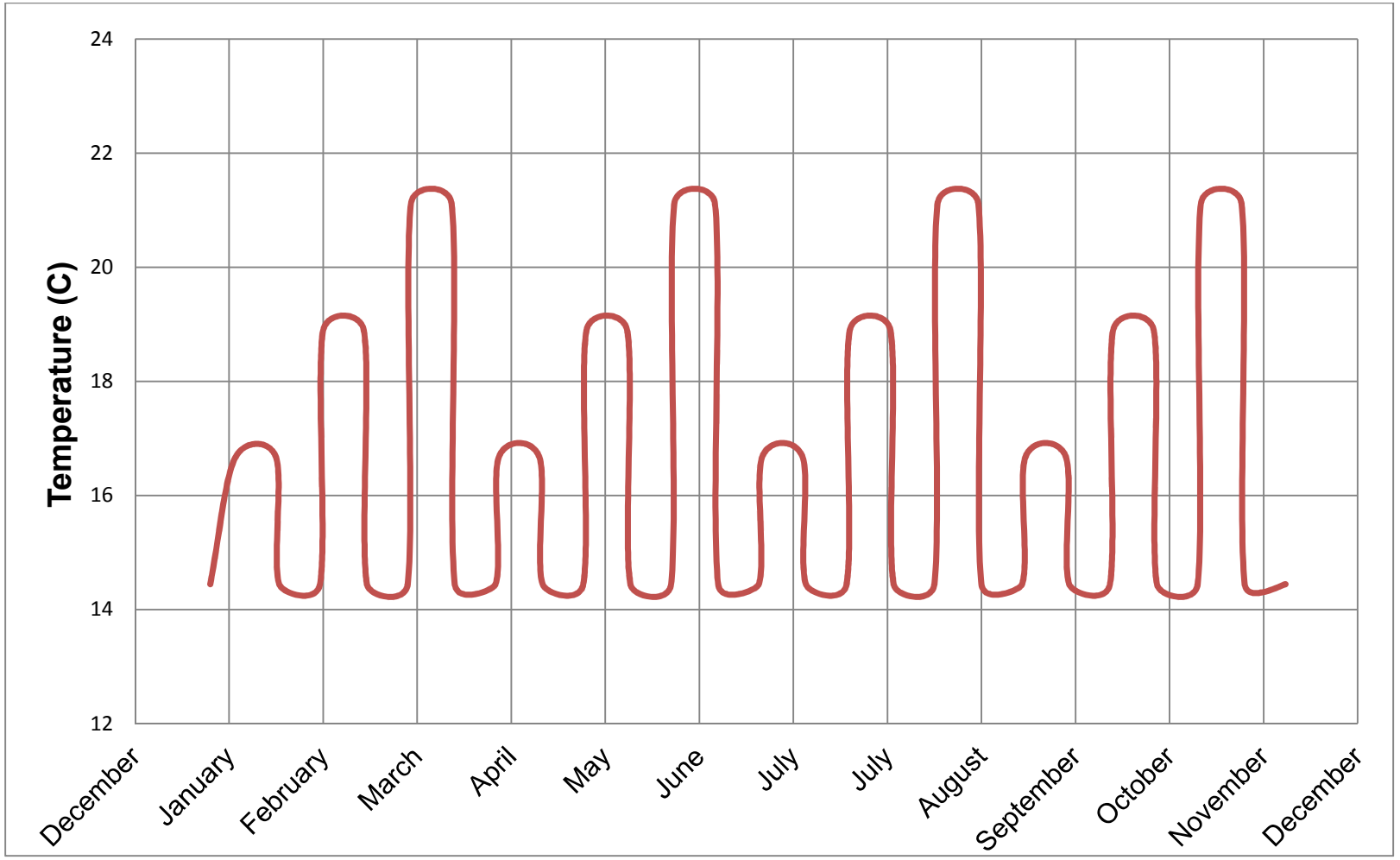

Figure 2.2: Desired temperature cycle for sweetpotato long-term storage under variable temperature conditions.

Figure 2.3: Controlled environment rooms for treated sweetpotatoes. a) NCSU campus storage room. b) Horticultural Research Station in Clinton, NC storage room.

The second experimental condition for 'Covington' sweetpotato roots was in commercial storage rooms, with storage capacity of up to 450,000 kg. The target temperature in commercial storage rooms was 14.4°C ±1˚C and 85% ±5% RH. Sweetpotato roots stored in commercial room were untreated, or kept under constant temperature, and served as control in the statistical analysis. Figure 2.4 shows the storage conditions in commercial facilities.

Figure 2.4: Commercial storage room for untreated sweetpotatoes. a) Common sweetpotato storage room in North Carolina. b) Sweetpotatoes after 10 months of storage in modern commercial storage facilities in North Carolina.

Roots from ‘Beauregard’, ‘Evangeline’, ‘Hatteras’, and ‘Carolina Rose’ sweetpotato cultivars were also stored at variable temperature conditions in controlled environment rooms on the campus of North Carolina State University in Raleigh, NC. The response to temperature stress of these four other sweetpotato cultivars would serve as comparison to the response of ‘Covington’ sweetpotatoes. This analysis is important to compare the responses of different genotypes to temperature stress during long-term storage.

The experiment was designed as a complete randomized design. Data analysis was conducted using the Statistical Analysis System version 9.3 for Windows (SAS Institute, Cary, NC). General linear models with mixed effects procedure was used, as was analysis of variance (ANOVA). The mean comparison of density by storage conditions, months stored and variety were analyzed. The differences found were statistically significant when $P<0.05$.

2.2.1 Materials

The varieties ‘Beauregard’, ‘Covington’, ‘Evangeline’, ‘Carolina Rose’ and ‘Hatteras’ sweetpotatoes for the variable storage temperature rooms were grown at the Lower Coastal Plain Tobacco Research Station in Kinston, North Carolina. They were then harvested simultaneously and cured immediately after harvest at the Horticultural Research Station in Clinton, North Carolina. ‘Covington’ roots stored in the semi-commercial storage room and treated with a variable temperature schedule were donated by Grower 2. ‘Covington’ sweetpotatoes stored in commercial rooms

were grown by the participating growers with facilities and fields located in eastern North Carolina. All of the roots included in this study were sweetpotatoes meeting U.S. No. 1 grade standards (United States Department of Agriculture. Agricultural Marketing Service, Fruit and Vegetable Programs. Fresh Produce Branch 2005).

The study was repeated two years, 2011 and 2012. During the first year, samples were taken from the five varieties stored in the on-campus controlled environment room after 3, 7 and 10 months of storage. Samples from the four growers' facilities were taken at 2, 3, 5, 7, 9 months of storage during that year. The second year a more comprehensive sampling schedule was developed; sampling from the five varieties stored in the on-campus controlled environment room before curing (BC), after curing (AC), and after 1, 2, 3, 5, 7, 8, 9, and 10 months of storage. Samples from the three growers' facilities and the semi-commercial controlled environment room at the Horticultural Research Crops in Clinton, NC were taken after 1, 2, 3, 4, 6, 8, 9, and 10 months of storage during the second year. At each sampling period, three samples were taken from each location and of each variety. Each sample consisted of two sweetpotato roots weighing from 250 to 350 g each randomly chosen, for a total of 351 samples. In addition to these samples, during the first year sampling periods, two 18 kg plastic lugs were filled with root sampled off the farms and along with the campus samples were taken to the NCSU Food Science Laboratories for quality testing. Two samples per plastic lug were collected for the laboratory analysis. Each sample was composed of seven or eight individual roots. Then the roots were washed, peeled and ground for chemical analyses that

included dry matter, starch, beta-carotene, vitamin C, sugars, and total phenolic content. The peeled roots were cut into 1.5 mm thick slices for testing on fried chips.

2.2.2 Density Measurement

Density was determined as the total weight of whole fresh sweetpotato (W_s) per unit volume. Since the volume of the specimen includes the volume enclosed by the external surface and the internal voids, the value measured corresponds to the apparent density (ρ_a) (Rahman 2009). Sweetpotato samples were taken to the laboratory, where each root was cleaned and weighted on a scale (ACBplus 1000, Adam Equipment, Danbury CT) with a resolution of 0.01 grams. The volume of the individual roots was determined by the liquid displacement method (Rahman 2009) by submerging individual roots in a 4,000 cc graduated cylinder (Nalgene-Thermo Fisher Scientific, Rochester, NY) containing 2,000 cc of tap water (Figure 2.5). The difference between the accumulated volume measured in the cylinder and the initial volume is the sweetpotato sampled volume (V_s). Tap water was replenished after measuring each sweetpotato. All measurements were taken at room temperature which was routinely measured using a digital thermometer (DTH700, General, New York City, NY) reporting 20°C ±1˚C. Density of sweetpotato (ρ_a) was calculated as:

$$\rho_a = \frac{W_s}{V_s} \tag{2.1}$$

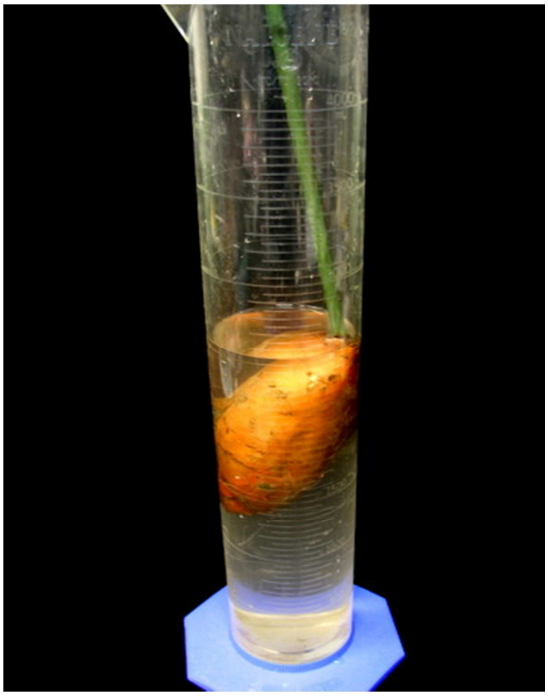

Figure 2.5 Sweetpotato inside graduated cylinder, measuring volume by displacement.

2.2.3 Nutrient Analysis

After measuring density as described further in the section below, 500 to 600 g of each sample were fine cut with a chopper (KFC3100ER, KitchenAid, St Joseph, MI), and stored in sealed bags at -40°C ±1˚C and 25% RH for 24 hours. This procedure would allow samples to freeze before being placed in the freeze dryer, in order to significantly reduce metabolic activity and efficiently freeze dry them. Some previously studied vegetables stored at -30˚C have shown 5% residual activity of

peroxidase, which did not affect quality during storage (Baardseth and Slinde 1980). Samples were freeze-dried and placed back in storage at -40˚C and 25% RH. When all the samples were collected, they were ground to 1 mm^2 particles in a laboratory grade grinder (1093 Cyclotec mill unit, Foss Tecator, Hoganas-Sweden). All of the 351 samples were scanned in a near-infrared-refractometer (NIR) (Foss XDS Nera-Infrared Rapid Content Analyzer XM-1100 series, Foss, Sweden). Samples that were the same as the samples from which their nutrients were chemically analyzed during the first year of the study were used to create a reference curve for the NIR analysis. Using the reference curve associated to the spectral data obtained from the initial samples, the NIR could then predict the nutrient values for the rest of the samples; However, in order to confirm the predicted values, chemical nutrient analysis was done to 20 samples (5%) from the experiment second year.

i. Chemical Analyses

The chemical analyses of the sweetpotato nutrients were conducted by two different sample preparations or methods. The first method was from fresh samples collected during the first year of the study. The second was from the randomly selected 5% of the total collected samples during the second year of the study, which were freeze-dried. Freeze dried sweetpotato samples were prepared in a freeze dryer (Model FFD-40-WS,The Virtis Company Inc., Gardiner, NY) for seven days with a condenser refrigeration temperature of -80 °C, shelf temperature of 2 °C and chamber pressure of 500 mm and stored at -40˚C. The results obtained from

dried samples were multiplied by their dry matter percentage to make them comparable to the results obtained from fresh samples. Only sugar content, beta-carotene, and phenolic acid tests were done on the freeze-dried samples. All of the analyses done from fresh samples were analyzed in duplicates. Freeze-dry samples were analyzed in triplicates.

Dry Matter Content

Dry matter content was determined as percentage of the total fresh weight, by obtaining the quotient of the dry weight by the fresh weight multiplied by 100. Fresh weight of the sample was measured by weighing sweetpotatoes after being chopped and bagged. Dry weight was obtained by weighting bagged samples immediately after being freeze-dried. Weight measurements of individual bagged samples were taken using a laboratory scale (ACBplus 1000, Adam Equipment, Danbury CT) with a resolution of 0.01 grams. The bags' weight was tared from the scale.

Brix Degrees

Brix degrees were measured by squeezing approximately three drops of sweetpotato juice out of the fresh ground sweetpotato on a digital hand held refractometer (PAL-1, Atago INC, USA). Sweetpotato tissue used from this procedure was randomly selected from the total ground sweetpotato sample. Approximately 100 g of sweetpotato tissue was placed in a gaze and squeeze to extract juice. This procedure was replicated twice per each sample.

Sugar

Five grams of freshly ground sweetpotato was placed in a centrifuge tube and mixed with 15 ml of 95% ethanol at 80˚C to 85˚C. The tube was left incubating for 10 minutes, then mixed on a vortex and 15 ml more of 95% ethanol was added. Subsequently, the tube was centrifuged for 10 minutes at 3,000 rpm, after that the supernatant was separated from the solid residues and brought to a 50 ml solution with 95% ethanol. This process resulted in a 1:10 dilution. Sugars were analyzed using a High Performance Liquid Chromatography (HPLC) (ThermoQuest, San Jose, CA) system consisting of a DGU-20a_3 degasser, LC 20AD pump, SIL-20AC HT auto sampler, CTO-20A column oven and a CBM-20A controller hooked to an Antec Leyden model Decade ll electromechanical detector in the pulse mode using a gold electrode. The wave form for the analysis was as follows, voltage (E) E_1 0.05V, E_2 0.75V and E_3 -0.80V. Time (t) settings for each setting of the wave form were respectively, t_1 500ms, t_2 130ms and t_3 130ms. The solvent was 0.15N NaOH, continually degassed by purging with UHP N_2 at 10ml/minute. The sugars were resolved on a CarboPac-1 -4x250mm with a 4x50mm guard column at a flow rate of 1.0ml/minute maintained at 30˚C. An internal standard of cellobiose was used for the quantization of the data. Picks were detected by a Diodex PAD (Pulse Amperometric Detector). All standard curves had a goodness of fit coefficient of at least 0.99 with the intercept being set to zero. The data acquisition and calculation software was by

Shimadzu, LabSolutions/LCsolutions 2003-2009.(Grabowski et al. 2008; Pattee et al. 2000)

For freeze-dried samples, the extraction started with 1g of freeze-dried sweetpotato powder and the rest of the process was the same as described above.

Starch

Starch content was determined using an assay kit (Megazyme International Ltd, Bray, Co. Wicklow, Ireland) according to AOAC Method 996.11(AOAC 1995). Fresh samples were first rinsed with ethanol to remove the sugars as described above. The remaining pellet was then treated with 2ml of dimethyl sulfoxide at 100°C to account for resistant starch. The samples were cooked with thermostable alpha amylase to partially hydrolyze and solubilize the starch. Subsequently, the samples were treated with amyloglucosidase for 30 minutes at 50°C to hydrolyze the starch dextrins to glucose. The samples were then transferred to 100ml volumetric flasks and filled to volume with distilled water. An aliquot of this solution was centrifuged at 3,000 rpm for 10 minutes and the supernatant transferred to a glass centrifuge tube. The solution was mixed with a glucose determination reagent and incubated at 50°C for 20 minutes. The absorbance of the solution at 510nm was read on a spectrophotometer (Cary 300 UV-Visible Spectrophotometer, Varian Inc., Palo Alto, CA) against a reagent blank. Starch content was calculated based on the absorbance of the sample with reference to a glucose standard. (Grabowski et al. 2008)

Vitamin C (Ascorbic Acid)

Five grams of fresh sweetpotato tissue ground from the Robot Coupe (Rotor Coupe RS1 2Y1, Rotor Coupe USA, Ridgeland, MS) were placed in about 15ml of 5% metaphosphoric acid, w/v. The sample was further macerated with a Tekmark grinder. Then the sample was centrifuged and filtered, the centrifugate precipitate was extracted two more times with the 5% solution of metaphosphoric acid. After that the solution was brought to a final volume of 50 ml. Vitamin C activity was quantified by determining the amount of ascorbic acid in the sample using an HPLC (ThermoQuest, San Jose, CA). Samples were maintained at 6°C in the auto-sampler tray with a light proof covering. 20µl samples were injected onto a 3µm reverse phase column (4.6 x 150mm) (µ Bondapack-NH_2 Z-module cartridge, Waters Associates, Milford, MA) and were separated at 30°C under isocratic conditions with an eluent flow rate of 1.0ml/minute. The mobile phase consisted of aqueous 0.005M KH_2PO_4 and acetonitrile (30:70 v/v). Peaks were monitored at 242nm by a UV 6000 uv/vis LP Diode Array Detector. Standard solutions with concentrations from 0.5mg/ml to 10mg/ml were used for the calculations. ThermoQuest Chromatography Data Acquisition Software version 4.1 was used to collect and process the data. Results were calculated using the external calibration method. The regression coefficient of the standard curve was greater than 0.99 with the intercept forced through zero. (Bode and Rose 1999; Grabowski et al. 2008)

Beta-carotene

Five grams of fresh sweetpotato tissue ground from the Robot Coupe were mixed with 40ml of hexanes-acetone (1:1) mixture and mixed on a vortex. The mixture was drawn under vacuum through a funnel with a fritted disk. The residue in the funnel was washed with 5ml of methanol and 50ml of the hexanes-acetone mixture two additional times or until the filter cake was colorless. The extract was transferred to a 250ml separatory funnel and washed with water. A few drops of saturated sodium chloride solution were added to the funnel to facilitate sharp delineation of the phases. The aqueous phase was released and the upper layer was transferred to a 50ml volumetric flask and brought to volume with hexane (Chandler and Schwartz 1988; Grabowski et al. 2008). Beta-carotene content was determined in the spectrophotometer (Cary 300 UV-Visible Spectrophotometer, Varian Inc., Palo Alto, CA) at 450nm. Beta-carotene content was calculated based on the absorbance of the solution.

For freeze-dried samples: The extraction started with 0.5g of freeze-dried sweetpotato powder, and the final solution was brought to a volume of 100ml. The rest of the process was the same described above.

Phenolics

Five grams of fresh sweetpotato tissue ground from the Robot Coupe were mixed with 15ml of a mixture composed of 7% acetic acid, 80% methanol, and 13%

water and mixed on a vortex. The tube containing the mixture was centrifuged for 10 minutes at 6,000 rpm at 10˚C. After that the supernatant was decanted and filtered 3 times. The remaining supernatant was brought to a volume of 50 ml. Phenolic content as chlorogenic acid was determined following the Folin-Ciocalteau procedure (Truong et al. 2007). Absorbance was read at 725 nm using a spectrophotometer (Cary 300 UV-Visible Spectrophotometer, Varian Inc., Palo Alto, CA). Phenolic content as chlorogenic acid was calculated based on the absorbance of the solution, and the regression coefficient of the standard curve with a regression coefficient greater than 0.99.

For freeze-dried samples: The extraction started with 1g of freeze-dried sweetpotato powder, and the rest of the process was the same described above.

Fat Percentage in Chips

Ten roots per plastic bin were randomly selected, washed with tap water and air dried. Cross sectional slices of the roots were cut and dip-fried in canola oil at 175˚C for 3 minutes. Then the chips were taken out of the oil and stored at room temperature. The fat content was analyzed using a Maran pulse Nuclear Magnetic Resonance, NMR (Resonance Instruments, Witney, Oxfordshire, UK). About 3 to 5 grams of chips were inserted in the NMR sample holder at room temperature, 20˚C ±1˚C. The results are the percentage of fat in relation to the weight of the chips. They were calculated using WinDXP software (Resonance Instruments, Witney, Oxfordshire, UK). Samples were analyzed in duplicates.

ii. Near-Infrared-Refractography Analysis

Freeze-dried sweetpotato powder in the amount of 15 to 30 g was deposited inside the sample cup which filled the cup to approximately 5 mm depth and then covered it with the lid. Next the cup was positioned in the NIR (Foss XDS Near-Infrared Rapid content analyzer XM-1100 series, Sweden) where the near-infrared spectrum was captured. The captured spectrums were compared to the spectrums from which data has been entered, and then the values corresponding to the new spectrums were calculated. The data acquisition software was ISIScan and the calculation software WinISI both by Foss, Sweden.

The results reported in this study were statistically significantly different when $p<0.05$. These results would determine the statistical difference in the two scenarios described previously. The first scenario was ‘Covington’ sweetpotatoes stored in variable temperature regimen, versus sweetpotatoes of the same variety stored in stable commercial conditions. The second situation was the comparison between five different sweetpotato cultivars, including ‘Covington’, stored in variable temperature regimen.

2.3. Results and Discussion

The measured temperature values for the two storage periods can be found in Appendix A. The desired variable temperature achedule had a mean temperature of 17˚C with a standard deviation (SD) of 2.3˚C and relative humidity 85% ±5%. This desired mean and SD temperature is comparable with the temperature measured in the on-campus controlled environment storage rooms. Furthermore, comparing the mean and SD temperature in variable storage conditions against the measured values in constant temperature commercial storage facilities, depicts clearly the differences between the two storage conditions. Measured mean temperature and relative humidity values for the variable temperature storage condition were as follows: On campus controlled environment room during 2011, temperature was 17.8˚C ±3.1˚C and RH 80.2% ±4.7%; during 2012, temperature was 17.2˚C ±2.8˚C and RH 81.7% ±3.1%. In the controlled environment room at the Horticultural Crops Research Station in Clinton, NC temperature was 19.8˚C ±2.2˚C and RH 73.8% ±3.3%.

Temperature, relative humidity and their respective standard deviation for the commercial facilities are shown in Table 2.1

Table 2.1: Temperature and relative humidity of commercial sweetpotato storage rooms.

	Temperature (˚C)	Relative Humidity (%)
Grower 1	14.2 ±1.1	81.2 ±9.1
Grower 2	14.9 ±1.2	83.9 ±4.7
Grower 3	15.9 ±1.5	79.3 ±4.0
Grower 4	14.1 ±1.1	77.4 ±4.8

From Table 2.1, notice the reduced temperature variation, and lower temperature magnitude in the commercial facilities, compared with values measured in the treated rooms.

Mean apparent densities and standard error calculations for 'Covington' sweetpotatoes before curing (B.C.), after curing (A.C.), and at different storage periods, up to 10 months, are listed in Table 2.2. Sweetpotatoes stored in a variable temperature schedule and sweetpotatoes stored in commercial conditions were significantly different ($p<0.05$) in density. The interaction of storage condition with months stored was highly significant ($p<0.0001$) at every level in the least square means comparison. Also the effect of storage time, measured in months, was highly significant.

Table 2.2: Apparent density of 'Covington' sweetpotatoes stored in variable temperature conditions, called treated, and 'Covington' sweetpotatoes store in stable commercial conditions, called control.

Before Storage				
	Kg/m^3	**±**		
B.C.	1045	9		
A.C.	1035	9		
During Storage				
	Control		**Treated**	
Months	**Kg/m^3**	**±**	**Kg/m^3**	**±**
1	984	12	1019	9
2	985	5	980	8
3	974	4	968	15
4	965	3	940	4
5	968	6	971	2
6	932	6	914	2
7	962	6	942	12
8	938	5	894	33
9	943	4	918	10
10	910	7	897	11

The rate at which treated sweetpotatoes lost density in the variable temperature storage, was almost twice the rate of density loss in the control or constant temperature storage. This could be explained by a more rapid use of energy reserves caused by the accelerated metabolic rates due to temperature stress. The weight loss rates were calculated as the slopes of the linear trends from the data

sets. Figure 2.6 shows the clear difference between the slopes of the control sweetpotatoes, -7.2, and treated sweetpotatoes, -11.9.

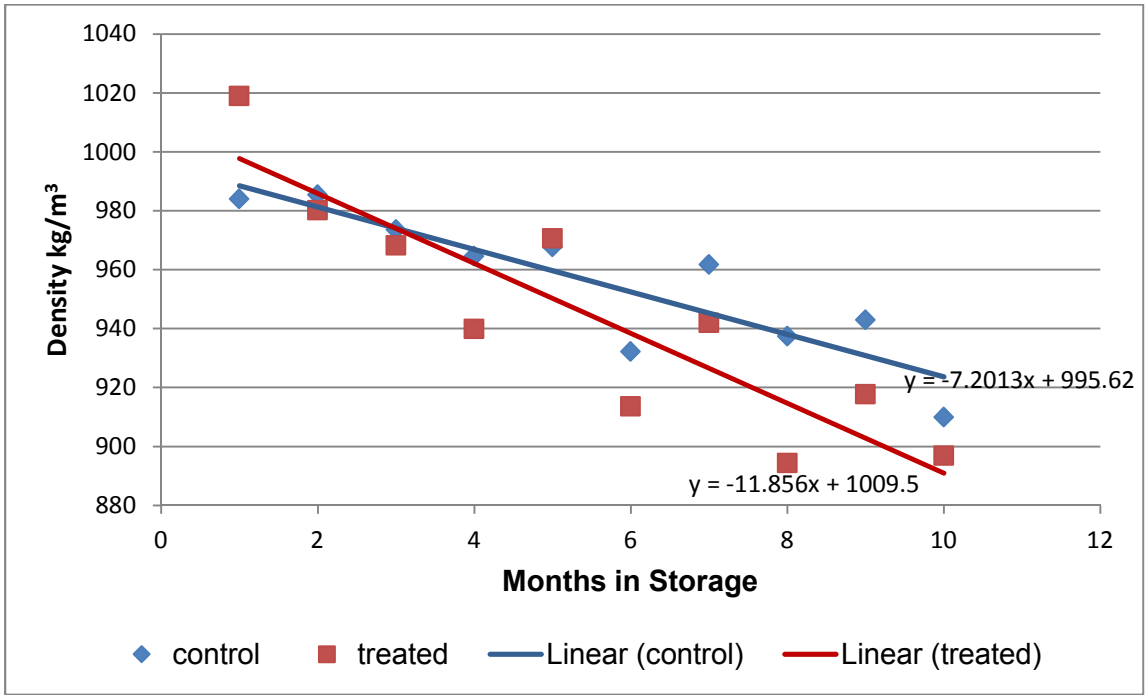

Figure 2.6: Apparent density of 'Covington' sweetpotatoes stored in variable temperature conditions, called treated, and 'Covington' sweetpotatoes store in stable commercial conditions, called control.

According to the data recorded, 'Covington' sweetpotatoes lost 1% of their density during curing. Then, after 10 months of storage, control 'Covington' lost 8% and treated 'Covington' lost 12% of their density. The density results correspond with density values for fresh vegetables (801-1095 kg/m^3) reported by Rahman (2009).

The results also correspond to the range reported by Stewart et al. (2000), and Kushman et al. (1966). Both authors also concluded that the rate of volume loss is less than the rate of weight loss, which would result in a decreased in the density.

The following density results for ‘Beauregard’, ‘Carolina Rose’, ‘Evangeline’, ‘Hatteras’, and ‘Covington’ sweetpotato cultivars under a variable temperature storage regimen is evidence of the influence of genotype on postharvest storage performance. Apparent densities for roots from the four cultivars, from B.C. to 10 months stored, are given in Table 2.3. Density (ρ_a) for all of the five cultivars stored under variable temperature was significantly affected by variety and storage period ($p<0.05$) in the ANOVA test. The interaction of variety and storage length had significant effects ($p<0.05$) as well. ‘Beauregard’ and ‘Carolina Rose’ lost 9% of their density over ten months of storage. ‘Evangeline’ lost 11%, and ‘Hatteras’ lost 17%. The curing process caused the density to decrease on the sweetpotato roots too, but this initial loss differed among the cultivars as follows: ‘Beauregard’ and ‘Covington’ loss 1% each, ‘Evangeline’ and ‘Hatteras’ loss 3%, and Carolina Rose 6%.

Table 2.3: Apparent density of four sweetpotatoes cultivars stored in variable temperature conditions.

	Beauregard		Carolina Rose		Evangeline		Hatteras	
Months	**Kg/m^3**	**±**	**Kg/m^3**	**±**	**Kg/m^3**	**±**	**Kg/m^3**	**±**
B.C.	1032	10	1090	36	1064	12	1049	7
A.C.	1025	1	1023	2	1032	4	1022	4
1	1026	11	1014	6	1039	9	1073	52
2	1009	1	1011	5	1025	10	1045	60
3	995	4	992	5	1025	11	951	26
5	974	11	973	6	1028	1	958	10
7	968	9	949	11	977	9	933	7
8	921	5	946	7	958	14	946	9
9	906	12	965	6	956	18	925	1
10	935	8	919	11	926	12	896	11

Some reduction in sweetpotato roots density during their postharvest life is unavoidable. However, good postharvest practices and correct variety selection, would minimize the density loss. Figure 2.7 shows the result of poor storage conditions on sweetpotatoes. When fully closed, these boxes easily hold 18kg of sweetpotatoes if they have been properly stored. However, for sweetpotatoes that have not been properly stored due to the decreased in density. The volume required is greater than the closed box volume, in order to obtain the required weight of 18 kg, the box must be over-filled, which prevent the box from being completely closed. In additon to the weight loss, due to the poor temperature management, the extra costs in freight and the increased risk of mechanical injury, would drastically reduce the profitability. This example shows the high density loss potential of sweetpotato under adverse condition, because they were 'Covington' stored 5 months with a measured density of 885 kg/m^3.

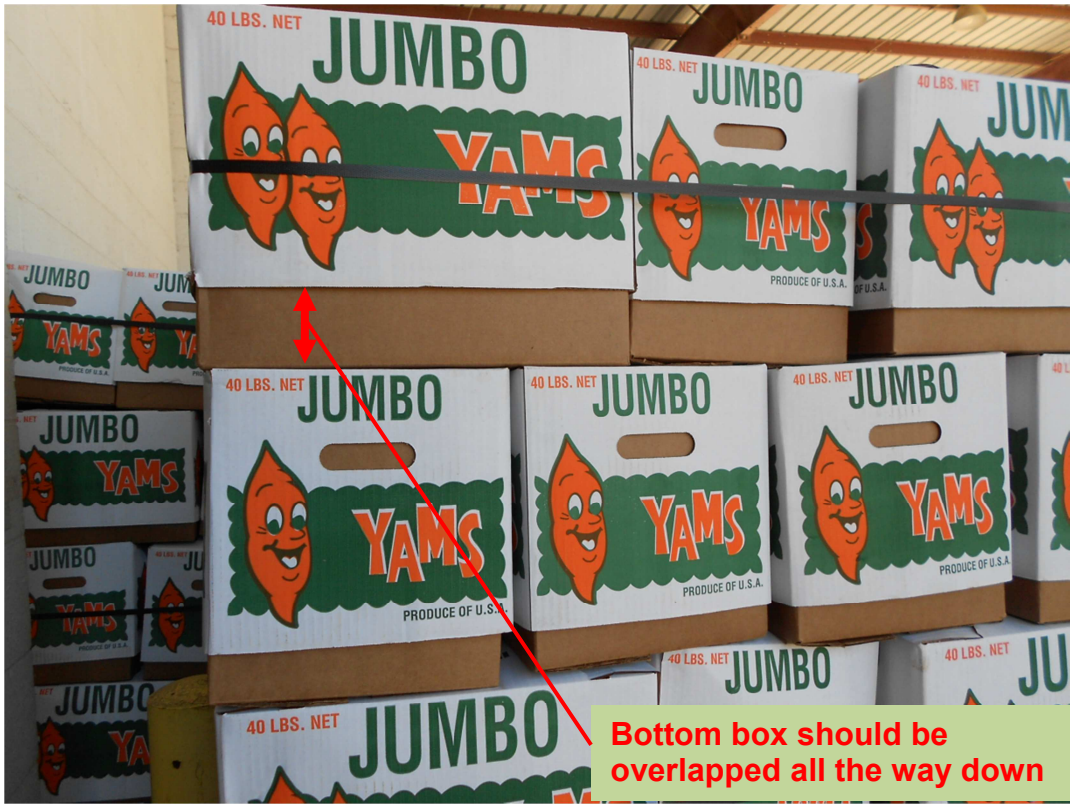

Figure 2.7: Commercial 18 kg sweetpotato boxes filled with low density roots.

The nutritional values for 'Covington' sweetpotatoes, stored under both conditions described above and for the other four varieties were calculated by chemical analysis and by applying NIR prediction techniques as described in the materials and methods section. The fitting statistics for the developed curve are reported in Table 2.4. The best prediction model was determined by the coefficient of determination (R^2) in the regression equation. When R^2 is closer to 1 the dependent function in the line equation is predicted better. Similarly, one minus the variation ratio (1-VR), predicts better values when it is closer to 1. Based on the two

previous parameters, and in the correlation of the results obtained by the two systems, the predicted values could be assessed as plausible. Only the R^2 value of maltose (0.24) could be in the unacceptable range. One of the reasons for this low values is that maltose content in sweetpotato roots is in the range of centesimal gram measure per 100 grams of fresh weight. This very low magnitude made the NIR system count some of the results as zero or no-result because of being below detectable limits; therefore, the dependent function in the regression equation is zero or non-existent, and the coefficient of determination is very low. Consequently, the input of maltose in the total sugars' content of sweetpotatoes could be considered low enough to be neglected.

Table 2.4: Fit statistics for Near-Infrared-Refractography prediction values curve.

Constituent	No. of Chemically Analyzed Samples	Mean	SD	Est. Min	Est. Max	SEC	R^2	SECV	1-VR	No. of Predicted Samples
Glucose	77	1.28	0.32	0.31	2.25	0.13	0.83	0.17	0.72	256
Sucrose	78	5.02	0.77	2.71	7.34	0.32	0.83	0.51	0.55	256
Fructose	77	0.99	0.29	0.11	1.86	0.13	0.79	0.17	0.65	256
Maltose	76	0.06	0.03	0.00	0.16	0.03	0.24	0.03	0.10	256
Tot. Sugar	79	7.36	0.68	5.32	9.41	0.21	0.91	0.52	0.42	252
Dry Matter	77	19.42	1.60	14.62	24.23	0.40	0.94	0.77	0.77	252
Brix	76	11.88	0.76	9.60	14.16	0.38	0.75	0.51	0.54	255
Starch	76	6.52	1.92	0.76	12.27	0.42	0.95	0.65	0.88	256
β-carotene	74	7.64	2.61	0.00	15.47	0.86	0.89	1.17	0.79	256
Phenolics	77	55.24	11.43	20.95	89.53	3.00	0.93	6.42	0.68	255
Vitamin C	77	6.25	1.59	1.49	11.00	0.75	0.78	1.07	0.53	256

SD= Standard Deviation
SEC= Crossed Standard Error
R^2= Coefficient of Determination
SECV= Standard Error of Cross Validation
1-VR= one minus variation ratio

The nutritional composition of 'Covington' sweetpotatoes stored under a variable temperature regimen, and in commercial conditions are reported in Table 2.5. The two nutritional traits that best relate to density are starch content (Figure 2.6), and fat percentage in chips (Figure 2.7). Sucrose was the more abundant sugar in 'Covington' sweetpotatoes and there was no statistically difference between treatments ($p=0.19$). Further, total sugars ($p=0.29$) and Brix degrees ($p=0.26$) were not statistically different among treatments. Beta-carotene, phenolic, and vitamin C content in the roots were statistically different ($p<0.05$), when the effect of the

treatment was dependent on storage time. Complete p-values and Duncan grouping (level 0.05) for ‘Covington’ treated and control sweetpotatoes are shown in appendix B.

Table 2.5: Nutritional composition and density of 'Covington' sweetpotatoes before curing (B.C.), after curing (A.C.) and during long-term storage, treated under a variable temperature storage regimen, and commercial conditions (control).

		Density		Dry Matter		Glucose		Sucrose		Fructose		Maltose		Total sugars	
		kg/m^3	±	%	±	g/100g	±	g/100g	±	g/100g	±	g/100g	±	g/100g	±
TREATED	B.C.	1045	9	23.7%	0.9%	1.28	0.08	4.07	0.04	1.12	0.03	0.04	0.01	6.51	0.13
	A.C.	1035	9	21.0%	0.0%	1.41	0.02	4.44	0.06	1.03	0.04	0.04	0.01	6.92	0.12
	2	1006	6	19.7%	0.3%	1.17	0.03	4.66	0.06	0.82	0.01	0.06	0.01	6.72	0.03
	3	913	62	23.5%	0.5%	1.47	0.13	4.86	0.68	1.31	0.11	0.05	0.00	7.68	0.44
	4	940	4	19.0%	0.4%	1.28	0.03	5.11	0.06	0.95	0.02	0.05	0.00	7.38	0.06
	5	971	2	18.7%	0.3%	1.08	0.01	5.06	0.17	0.83	0.01	0.06	0.00	7.03	0.18
	6	914	2	18.7%	0.3%	1.27	0.02	5.06	0.05	0.94	0.01	0.05	0.00	7.33	0.04
	7	930	19	21.8%	0.8%	1.45	0.17	5.06	0.21	1.10	0.13	0.06	0.01	7.68	0.48
	9	922	11	18.7%	0.4%	1.11	0.04	4.87	0.10	0.84	0.02	0.08	0.01	6.90	0.12
	10	902	13	20.1%	0.6%	1.26	0.08	4.93	0.08	0.94	0.07	0.07	0.00	7.19	0.11
CONTROL	1	984	12	20.9%	0.5%	1.29	0.03	4.96	0.04	1.04	0.02	0.05	0.00	7.34	0.07
	2	996	9	21.1%	0.7%	1.19	0.04	5.59	0.11	1.08	0.04	0.06	0.00	7.92	0.12
	3	967	1	21.0%	1.0%	1.08	0.02	5.50	0.00	0.88	0.02	0.06	0.01	7.52	0.03
	4	965	3	19.0%	0.0%	1.29	0.02	5.15	0.09	0.98	0.01	0.05	0.00	7.46	0.08
	5	968	6	19.2%	0.3%	1.15	0.03	5.25	0.12	0.88	0.02	0.06	0.00	7.33	0.11
	6	932	6	18.4%	0.4%	1.23	0.04	4.90	0.09	0.95	0.02	0.05	0.01	7.12	0.08
	7	962	6	19.1%	0.3%	1.06	0.04	4.35	0.07	0.77	0.03	0.08	0.00	6.26	0.09
	9	943	4	18.9%	0.6%	1.19	0.03	5.11	0.12	0.93	0.02	0.07	0.00	7.29	0.13
	10	910	7	19.3%	1.0%	1.12	0.03	4.91	0.14	0.92	0.02	0.08	0.00	7.03	0.18

Table 2.5 Continued.

		Brix		Starch		Beta-carotene		Phenolics		Vitamin C		Fat in Chips	
		deg	±	g/100g	±	mg/100g	±	mg Chlorogenic acid/100g	±	mg/100g	±	%	±
TREATED	B.C.	10.30	0.13	8.82	0.11			57.20	1.11	.	.	.	.
	A.C.	10.97	0.07	7.39	0.43			64.92	2.81	.	.	.	.
	2	12.05	0.17	6.04	0.36	8.24	0.09	66.43	1.97	.	.	.	.
	3	11.01	0.59	9.47	0.67			36.90	1.64	5.14	0.04	36.5	0.5
	4	12.08	0.07	5.44	0.12	7.31	0.35	59.39	1.47	.	.	.	.
	5	12.03	0.10	5.37	0.10	8.17	0.51	61.20	0.39	.	.	.	.
	6	12.02	0.06	4.83	0.18	7.93	0.11	55.11	2.36	.	.	.	.
	7	12.10	0.07	5.88	0.51	7.19	0.57	61.28	1.32	5.08	0.47	38.9	0.8
	9	12.04	0.12	4.52	0.10	8.40	0.22	56.27	1.42	.	.	.	.
	10	12.16	0.09	4.32	0.33	8.74	0.20	57.83	1.55	6.40	0.03	42.1	0.3
CONTROL	1	11.22	0.14	7.91	0.12			56.53	1.71				
	2	11.77	0.10	7.03	0.28			50.47	1.83	6.28	0.23	36.8	0.4
	3	11.27	0.43	6.24	0.32			45.90	1.39	6.99	0.55	40.5	0.9
	4	12.00	0.12	5.72	0.25	7.31	0.26	62.33	2.29	.	.	.	.
	5	12.12	0.18	5.58	0.26	7.07	0.20	67.17	1.91	8.96	0.24	40.8	0.6
	6	11.71	0.19	4.69	0.18	7.14	0.21	51.58	1.48	.	.	.	.
	7	11.70	0.20	4.90	0.21	7.79	0.23	51.08	1.71	4.49	0.17	41.6	0.4
	9	11.87	0.12	4.74	0.16	7.72	0.13	46.99	1.12	6.24	0.14	44.0	0.4
	10	12.27	0.11	4.17	0.23	7.88	0.17	58.70	2.51	.	.	.	.

Starch content in both the treated and control sweetpotatoes was statistically different ($p<0.05$) when the effect of treatment was dependent on storage time. Since time affected density directly, it was possible to correlate starch content with density (Figure 2.8). Density would be an indicator of starch content, and change of density during storage time could be used to estimate the starch content. Figure 2.8, shows the relation between density and grams of starch per 100 grams of fresh 'Covington' sweetpotato. Thus, the data showed that for each 10 kg/m^3 decrease in apparent density the 'Covington' sweetpotatoes lose approximately 2 g/100g of starch with a coefficient of determination (R^2) of 70%.

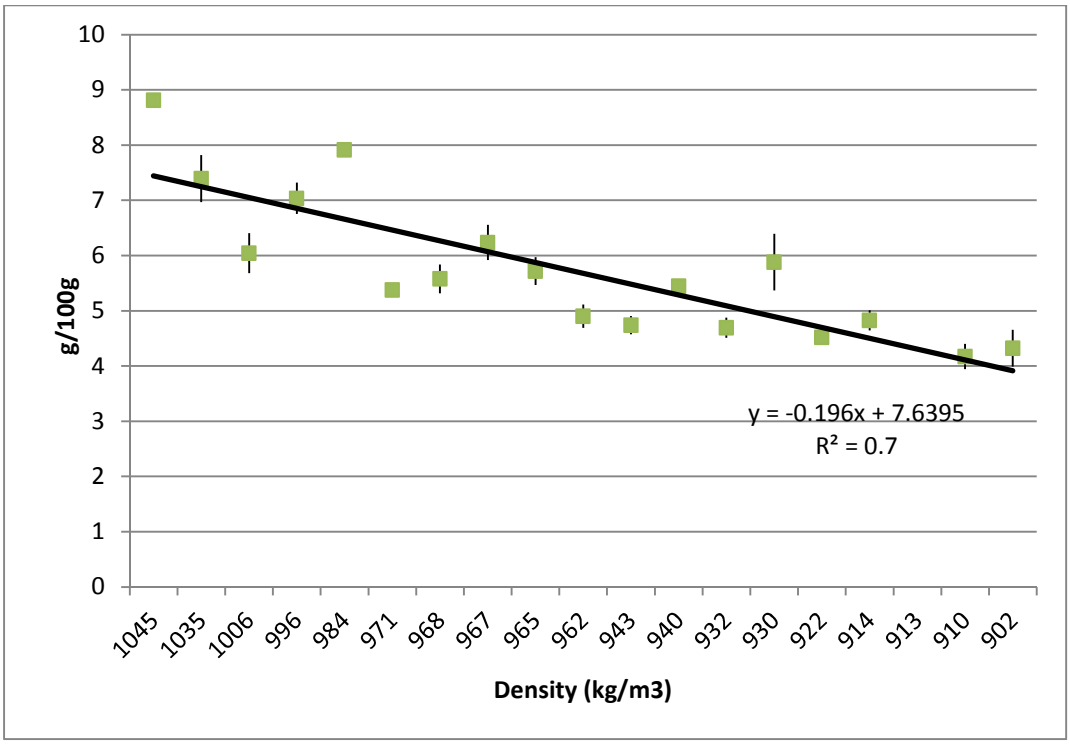

Figure 2.8: Starch content of 'Covington' sweetpotatoes at different density levels.

Fat percentage content in chips of 'Covington' sweetpotatoes was directly related to density; as density decreased, fat percentage in chips increased. Figure 2.9, shows that the increase rate of fat absorption in treated (2.78) 'Covington' sweetpotatoes is almost twice the increase rate in the control (1.54). In the ANOVA analysis the fat percentage content in 'Covington' sweetpotato chips was statistically significative ($p<0.05$).

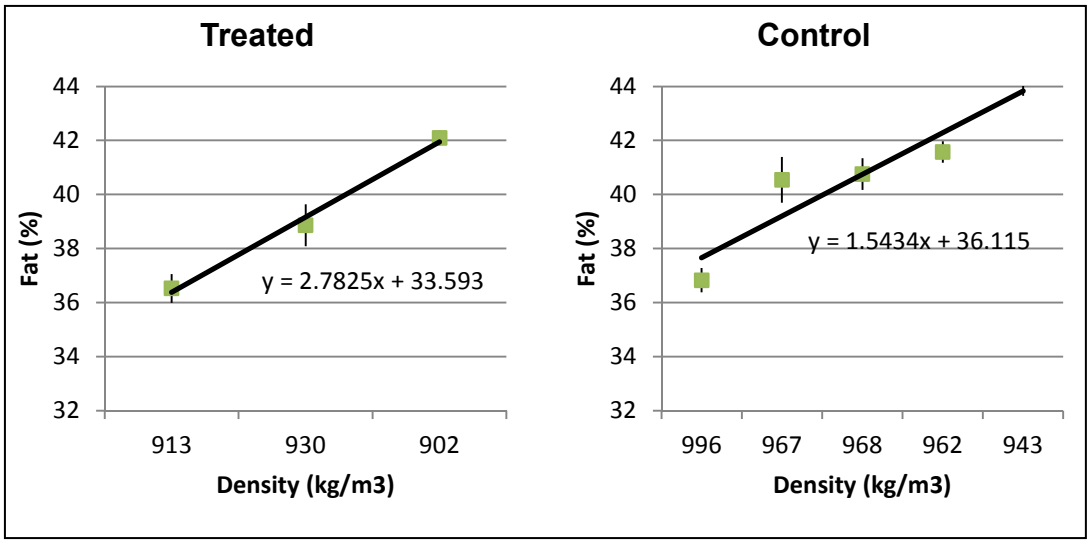

Figure 2.9: Fat percentage in chips of 'Covington' sweetpotatoes at different density levels.

The nutritional composition of 'Beauregard', 'Carolina Rose', 'Evangeline', and 'Hatteras' sweetpotatoes stored under a variable temperature regimen is summarized in Table 2.6. The analysis of variance (ANOVA) showed that the effect of variety on all the analyzed nutritional characteristics were statistically significant ($p<0.05$). When the effect of variety was dependent on storage time, p values were statistically significant for all the analyzed traits, except dry matter (p=031) and maltose (p=0.13) content. Dry matter is expected to be constant over time as a consequence of homeostasis (Kays 2004). On the other hand the very low values of maltose (0.01 to 0.05 g/100 grams of fresh sweetpotato root) made it impossible to establish a clear difference in content among varieties over storage time. The two nutritional traits that best relate to density are starch content and fat percentage in

chips. As ‘Beauregard’ lost 36% of starch, its fat in chip content rose 22%. ‘Carolina Rose’, ‘Evangeline’, and ‘Hatteras’ lost 34%, 48% and 37% starch content respectively, while their fat in chips content increased 20%, 29% and 20%, respectively. Total sugars, Brix degrees, beta-carotene, phenolic, and vitamin C contents were affected and statistically significant ($p<0.05$) by variety but it was not possible to establish a correlation of these nutritional traits neither over time nor density. The difference in sugars among the analyzed varieties was in the amount of glucose, sucrose and fructose in each cultivar (Figure 2.10). ‘Hatteras’ was the highest variety in glucose and fructose content, while its sucrose content was the lowest. ‘Covington’ had the largest mean content of sucrose, followed by ‘Evangeline’, this last cultivar had the lowest mean content of glucose and fructose. ‘Beauregard’ mean content of the different sugars were in mid-range in comparison with the other varieties. ‘Carolina Rose’ had the lowest mean content in glucose and fructose, being the second lowest to ‘Hatteras’ in mean sucrose content. Complete p-values and Duncan grouping (level 0.05) for ‘Beauregard’, ‘Carolina Rose’, ‘Evangeline’, and ‘Hatteras’ sweetpotatoes stored under a variable temperature are in Appendix C.

Table 2.6: Nutritional composition and density of four sweetpotato varieties treated under a variable temperature storage regimen, before curing (B.C.), after curing (A.C.), and during long-term storage.

		Density		Dry Matter		Glucose		Sucrose		Fructose		Maltose		Total sugars	
		kg/m^3	±	%	±	g/100g	±	g/100g	±	g/100g	±	g/100g	±	g/100g	±
BEAUREGARD	B.C.	1032	9	19.3%	0.3%	1.40	0.05	4.75	0.07	1.14	0.04	0.03	0.00	7.32	0.16
	A.C.	1025	1	19.3%	0.9%	1.45	0.13	4.30	0.15	1.12	0.09	0.03	0.01	6.90	0.10
	2	1009	1	19.0%	0.0%	1.76	0.04	2.80	0.28	1.24	0.03	0.03	0.01	5.83	0.28
	3	988	2	22.3%	0.3%	1.51	0.03	4.65	0.18	1.26	0.04	0.03	0.01	7.45	0.12
	5	974	11	17.0%	0.6%	1.64	0.06	2.72	0.18	1.13	0.07	0.04	0.00	5.54	0.30
	7	968	8	20.7%	0.7%	1.51	0.04	4.12	0.35	1.07	0.04	0.04	0.01	6.74	0.37
	9	906	12	17.7%	0.7%	1.62	0.04	3.77	0.32	1.09	0.09	0.05	0.01	6.53	0.41
	10	950	13	19.3%	1.0%	1.49	0.07	3.90	0.09	1.01	0.07	0.05	0.00	6.45	0.09
CAROLINA ROSE	B.C.	1090	35	22.0%	1.5%	1.56	0.05	3.90	0.14	1.23	0.03	0.02	0.01	6.71	0.15
	A.C.	1023	2	19.0%	0.6%	1.36	0.01	4.01	0.14	0.96	0.03	0.01	0.00	6.34	0.16
	2	1011	5	17.7%	0.3%	1.51	0.04	3.66	0.17	1.04	0.01	0.03	0.01	6.24	0.13
	3	992	5	22.7%	0.3%	1.34	0.04	5.31	0.23	1.18	0.03	0.05	0.01	7.87	0.28
	5	973	6	17.7%	0.3%	1.31	0.05	3.45	0.23	0.92	0.04	0.04	0.00	5.72	0.23
	7	949	11	19.7%	0.7%	1.30	0.09	4.77	0.56	0.87	0.08	0.04	0.00	6.97	0.67
	9	966	6	16.7%	0.3%	1.38	0.02	3.82	0.16	0.78	0.02	0.03	0.00	6.02	0.16
	10	919	11	20.0%	1.1%	1.23	0.02	4.49	0.31	0.83	0.01	0.04	0.01	6.60	0.31

Table 2.6 Continued.

		Density		Dry Matter		Glucose		Sucrose		Fructose		Maltose		Total sugars	
		kg/m^3	±	%	±	g/100g	±	g/100g	±	g/100g	±	g/100g	±	g/100g	±
EVANGELINE	B.C.	1064	12	21.0%	1.5%	1.44	0.03	3.61	0.12	1.00	0.05	0.01	0.00	6.07	0.15
	A.C.	1032	4	25.7%	3.2%	1.34	0.07	3.83	0.08	0.93	0.06	0.02	0.01	6.12	0.20
	2	1025	10	20.3%	1.2%	1.22	0.11	4.29	0.20	0.84	0.10	0.04	0.00	6.38	0.39
	3	1031	7	25.3%	1.2%	1.02	0.02	5.69	0.17	0.91	0.05	0.04	0.00	7.66	0.24
	5	1028	1	22.0%	1.5%	1.11	0.04	3.68	0.21	0.68	0.03	0.04	0.01	5.52	0.19
	7	977	9	21.0%	0.5%	0.97	0.10	5.19	0.66	0.68	0.06	0.05	0.00	6.88	0.56
	9	956	18	20.0%	1.0%	1.24	0.03	4.29	0.28	0.70	0.05	0.04	0.01	6.27	0.35
	10	926	12	22.0%	2.8%	0.90	0.08	4.53	0.40	0.59	0.04	0.04	0.00	6.06	0.34
HATTERAS	B.C.	1049	7	20.7%	0.3%	1.52	0.10	3.31	0.05	1.23	0.09	0.04	0.01	6.10	0.24
	A.C.	1022	4	21.3%	0.3%	1.84	0.06	3.55	0.06	1.51	0.05	0.04	0.01	6.93	0.15
	2	1045	60	21.0%	1.5%	1.91	0.02	2.54	0.09	1.47	0.03	0.04	0.01	5.95	0.05
	3	929	54	23.0%	1.5%	1.92	0.03	4.53	0.13	1.70	0.03	0.03	0.01	8.18	0.16
	5	959	10	20.0%	0.6%	1.86	0.04	2.88	0.05	1.45	0.03	0.05	0.00	6.24	0.09
	7	934	7	21.7%	0.8%	1.84	0.04	3.38	0.20	1.45	0.02	0.06	0.00	6.72	0.19
	9	925	1	18.3%	0.7%	1.86	0.03	3.29	0.11	1.39	0.03	0.06	0.01	6.60	0.08
	10	911	18	20.0%	1.0%	1.89	0.04	3.73	0.18	1.42	0.04	0.05	0.00	7.09	0.26

Table 2.6 Continued.

		Brix		Starch		Beta-carotene		Phenolics		Vitamin C		Fat in Chips	
		deg	±	g/100g	±	mg/100g	±	mg Chlorogenic acid/100g	±	mg/100g	±	%	±
BEAUREGARD	B.C.	10.58	0.13	8.99	0.14	6.04	0.41	72.70	3.41	.		.	
	A.C.	10.40	0.19	8.10	0.59	6.84	0.62	63.20	2.22	.		.	
	2	10.97	0.17	7.68	0.51	7.70	0.46	74.83	2.39	.		.	
	3	10.65	0.15	10.01	0.09	3.52	0.12	41.37	2.19	4.65	0.01	33.8	0.2
	5	10.86	0.12	6.67	0.27	8.53	0.15	59.43	4.72	.		.	.
	7	11.07	0.17	6.97	0.42	7.32	0.73	56.85	3.80	8.08	0.05	37.5	0.7
	9	10.56	0.06	5.88	0.72	9.65	0.60	52.55	2.57	.		.	.
	10	11.15	0.14	5.78	0.30	9.26	0.61	55.48	1.43	6.75	0.29	41.1	0.3
CAROLINA ROSE	B.C.	10.37	0.03	8.75	0.20	5.70	1.00	58.55	2.20	.		.	.
	A.C.	10.83	0.06	7.79	0.68	8.52	0.24	54.30	3.04	.		.	.
	2	11.35	0.26	7.97	0.30	10.74	0.24	56.47	0.25	.		.	.
	3	11.22	0.10	10.02	0.10	4.35	0.10	43.63	1.45	5.34	0.51	34.7	0.2
	5	11.29	0.15	7.43	0.19	11.22	0.12	57.89	3.61	.		.	.
	7	11.57	0.29	6.76	0.44	10.26	0.58	54.52	2.30	4.30	0.02	38.6	0.5
	9	11.29	0.10	4.88	0.24	13.12	0.11	50.35	3.13	.		.	.
	10	11.94	0.25	5.81	0.25	11.89	0.31	56.53	1.83	6.71	0.06	41.7	0.4

Table 2.6 Continued.

		Brix		Starch		Beta-carotene		Phenolics		Vitamin C		Fat in Chips	
		deg	±	g/100g	±	mg/100g	±	mg Chlorogenic acid/100g	±	mg/100g	±	%	±
EVANGELINE	B.C.	11.03	0.34	6.71	0.22	8.66	0.26	63.84	5.19	.	.	.	.
	A.C.	11.26	0.14	6.80	0.58	6.78	0.37	61.90	3.62	.	.	.	.
	2	12.18	0.39	7.14	0.42	10.76	1.11	83.07	5.55	.	.	.	.
	3	12.07	0.05	9.92	0.33	6.25	1.30	47.71	1.98	5.50	0.33	32.0	0.3
	5	12.18	0.17	4.64	0.36	11.52	0.48	77.99	2.79	.	.	.	.
	7	12.73	0.10	6.12	0.50	12.49	0.40	79.44	2.93	7.26	0.87	36.4	0.1
	9	12.38	0.39	3.53	0.61	11.75	1.47	79.91	6.04	.	.	.	.
	10	12.82	0.18	3.49	0.50	14.15	0.66	88.17	3.11	6.72	0.31	41.3	0.1
HATTERAS	B.C.	10.52	0.04	8.86	0.46	7.54	0.44	57.73	2.78	.	.	.	.
	A.C.	10.25	0.09	9.09	0.29	4.73	0.60	59.28	0.62	.	.	.	.
	2	11.22	0.06	8.03	0.34	8.38	0.62	65.45	2.35	.	.	.	.
	3	10.55	0.07	9.83	0.22	5.12	0.74	43.51	3.17	4.44	0.13	35.4	1.1
	5	11.40	0.16	7.15	0.16	9.17	0.36	74.90	4.42	.	.	.	.
	7	11.60	0.11	7.37	0.41	8.65	0.31	66.67	1.55	6.80	0.93	39.2	0.5
	9	11.27	0.18	4.87	0.30	10.87	0.21	74.49	0.97	.	.	.	.
	10	11.65	0.16	5.56	0.51	10.07	0.41	73.19	3.53	6.51	0.07	42.5	0.4

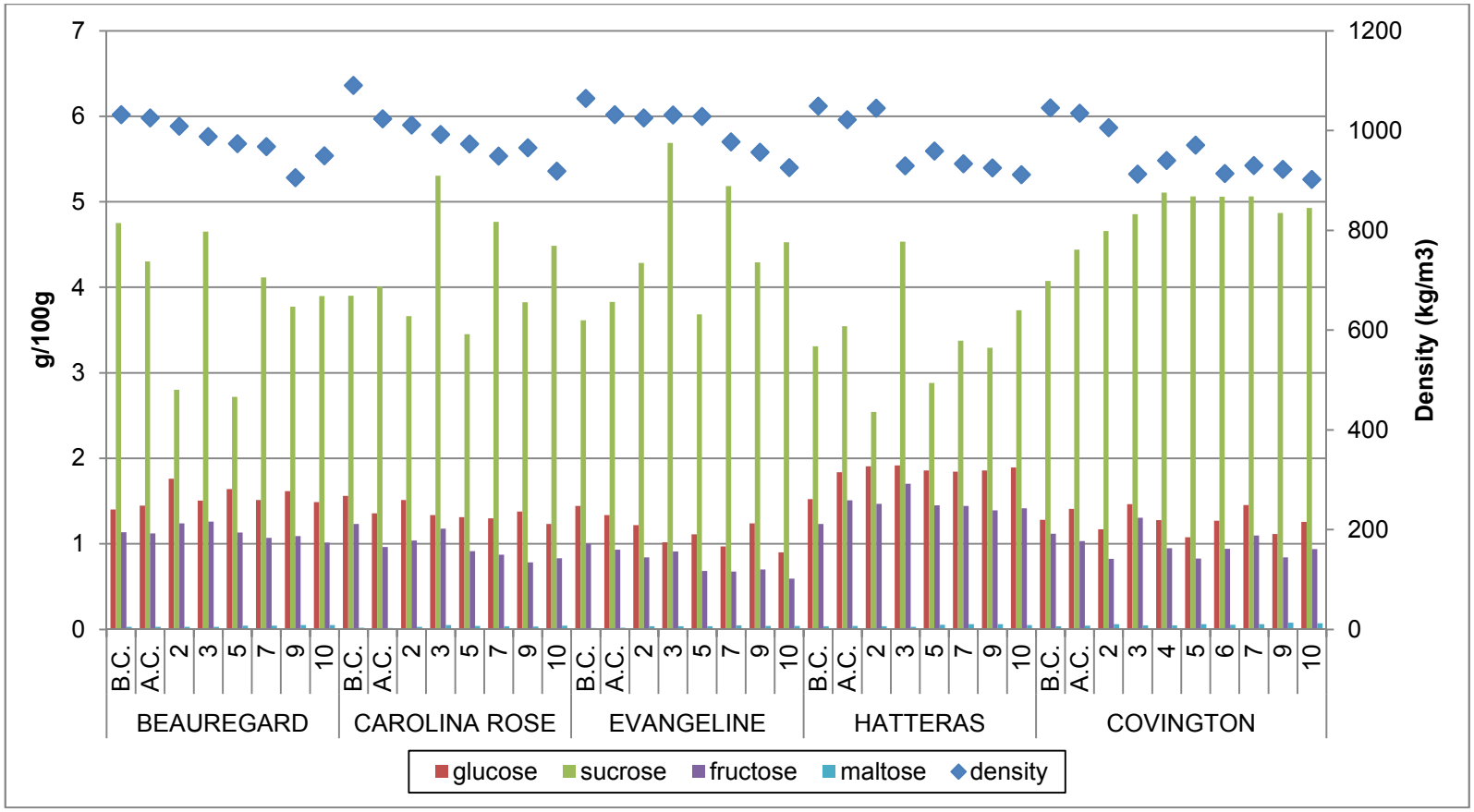

Figure 2.10: Glucose, sucrose, fructose and maltose content and density, of the five sweetpotato varieties, before curing (B.C.), after curing (A.C.), and during long-term storage.

2.4. Conclusions

The properties quantified in this study had not been measured in sweetpotatoes during storage. From the results obtained, it is possible to conclude that the two factors that contribute the most to post-storage quality of sweetpotatoes are temperature and genotype.

Density could be the best non-destructive test to assess the overall quality of the sweetpotato storage, length of storage, nutritional values, and general postharvest handling of sweetpotato roots. Density decreases over time, and it decreases faster when storage conditions are inadequate for sweetpotato roots. The difference in the density time rate of change between 'Covington' sweetpotatoes stored under a variable temperature regimen and in commercial conditions validated the effect of improper temperature management during storage. Therefore, it would be safe to assume that the change in density would be smaller in 'Beauregard', 'Carolina Rose', 'Evangeline', and 'Hatteras', if they were stored under recommended commercial conditions.

The reduction in density over time in 'Covington' sweetpotatoes constitutes a benchmark standard to assess the length and conditions of storage for 'Covington' sweetpotatoes. Density would better describe the change in starch content and fat percentage in chips for sweetpotato; although, sugars, starch, beta-carotene, phenolic and vitamin C content could also be estimated from this study.

Near-Infrared-Refractography (NIR) prediction system has been proven to be accurate in predicting the chemical content of sweetpotatoes as long as a good content prediction curve is developed. Periodical chemical analysis would be recommended when this system is used, in order to verify the precision of the predicted values and improve the prediction curve. NIR is a fast, and a low cost analysis, which provides the capability to examine more samples.

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CHAPTER 3

Prediction Model for Sweetpotato *(Ipomoea batatas (L) Lam)* Weight loss During Long-term Storage

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Abstract. This paper describes work to develop mixed effects statistical models to predict weight loss of five different sweetpotato varieties (*Ipomoea batatas* (L) Lam), 'Beauregard', 'Carolina Rose', 'Covington', 'Evangeline', and 'Hatteras' during long-term storage as a result of temperature and water stresses. The models were developed using the Statistical Analysis System, SAS, version 9.3 for Windows. Linear mixed models were fit using the MIXED procedure. The sweetpotato roots used in the study were grown and stored in eastern North Carolina and were all U.S. No 1 grade. The roots were stored in two different controlled environment rooms. In the first controlled environment room, the temperature was held constant at 14.1˚C ±0.1˚C while relative humidity (RH) was maintained at selected values ranging 65% to 85%. The relative humidity inside this storage room was sequentially changed in 90 day cycles. Each cycle was divided into three 30 day periods. During each period, the relative humidity was initially held constant at 85%, then decreased to 75%, and finally 65%. A total of three cycles and an additional period at 85% RH were necessary to complete 300 days of storage. In the second controlled environment room, relative humidity was held constant at 85% ±5% but temperature was varied. The temperature inside this second room was changed in cycles from 14.4˚C to 21˚C. Each temperature cycle lasted 90 days and was divided into of 15 day periods. Each 15 day period had constant temperatures in the following order: 14.4˚C, 17˚C, 14.4˚C, 19˚C, and finally back to 14.4˚C. The temperature, RH and variety all had significant ($P<0.05$) effects on estimated values. Under the variable temperature storage conditions, 'Covington' and 'Beauregard' experienced the

lowest rate of weight loss relative to the others. ‘Carolina Rose’ and ‘Hatteras’ experience the greatest rates of weight loss. In the variable temperature storage conditions ‘Covington’ and ‘Beauregard’ had the lowest weight loss rates, while ‘Hatteras’ appeared to benefit the most from increased relative humidity, with ‘Carolina Rose’ the least. Statistical models that predict sweetpotato weight loss during long-term storage based on environmental conditions could be used to forecast shrinkage of roots and better plan business decisions as well as supply requirements from field production or packing houses.

3.1. Introduction

Storing sweetpotato for long periods is a common practice for growers and packers. Like all living tissue, the sweetpotato roots continue their metabolic processes in storage. One of the most important metabolic processes is respiration, where molecules of oxygen from the air are taken for the oxidation processes and the enzymes alpha and beta amylases are secreted (Kays 2004). The enzymes metabolize starch into sugar and in this way the sweetpotato obtains the energy to remain alive. Respiration results in weight loss with its magnitude determined by the respiration rate and time (Fonseca et al. 2002). In general practice, the respiration rate is determined by the storage temperature, the relative humidity and the specific cultivar.

Postharvest physiological stresses associated with long-term storage of sweetpotatoes are mainly thermal and water related. Optimum storage temperatures for sweetpotatoes have been establish in numerous studies going back nearly a century to within the range of 13˚C to 15˚C, with chilling injuries caused by temperatures below 10˚C. Above 15˚C the rate of respiration increases with the increased likelihood for sprouting to commence. The optimum recommended relative humidity is 85% to 90% (Wilson 1989; Kays 2004; Afek and Kays 2004; Kader 2002; Boyette 1997; Kushman and Wright 1969).

Shrinkage of sweetpotato roots during long-term storage under non-ideal temperature conditions have been reported to be as much as 18% of the total weight

over several months, while sweetpotatoes stored in ideal conditions have been as little as 5% loss of the initial stored weight after 10 months (Garzon 2012). Figure 3.1, illustrates the different outcomes from modern well managed storage facilities as compared to facilities that lack the ability to accurately control environmental factors. In a recent study supermarkets reported an average loss on fresh sweetpotato roots of 15.2% in 2005 and 13.2% in 2006 (Buzby et al. 2009). Although, the reported data shows some improvement due probably to more conscientious handling, losses are still greater than desired. The report cited above included losses from decay, poor handling and other factors in addition to losses due to respiration However, the prediction model in the present study refers only to losses due to respiration. Providing the roots with proper handling would help reduce losses due to the other factors. Both studies cited show the consequences and realities of postharvest handling of sweetpotatoes and shows the need of a tool to help predict the losses. A prediction model could provide information to sweetpotato handlers concerning temperature and relative humidity effect on the quality of roots and potential marketing impacts. A prediction model could also help growers, packers and industry representatives to forecast the shrinkage of sweetpotatoes under various storage conditions and consequently adjust supply levels to their needs.

In science and engineering models are used to represent some real-world process in a more convenient and cost-effective way than the actual process (Taylor et al. 1993). There are many different kind of models depending on the desired

application. Neelamkavil (1987) classified models in three categories: physical, symbolic and mental. From this classification, symbolic models were sub-classified as mathematical or non-mathematical (Neelamkavil 1987). In our specific case, in order to describe product loss over time, the appropriate model category would be restricted to a mathematical/statistical model based on empirical data. The data used to develop the model described in this paper was obtained from experiments conducted and replicated over several years.

When collecting sequential data, the theory suggests that it should have parameters that are possible to estimate (Nelder 1992) and the estimated parameters should reflect the results obtained from the process. Biological processes have intrinsic variance and this variance can complicate the statistical and conceptual analysis of the data (Hertog et al. 2007). Therefore with the purpose of establishing the relationship between weight loss and storage time influenced by temperature and relative humidity, it is necessary to have a clear understanding of the process and enough representative data for the analysis. Further, mixed effects statistical models can include fixed and random effects (Laird and Ware 1982). Experimental fixed and random components or classes could enter the model in linear (Verbeke and Molenberghs 2009) and nonlinear (Pinheiro and Bates 2000) modes.

The purpose of the mixed effects model is to elaborate an analysis that would describe the average behavior of the subject of the study by taking into account the

effect of individual classes and their relationship with serial observations. Biological systems' variance depends on the natural heterogeneity of the population and the heteroscedaticity (non-constant variance) of the data (Hertog et al. 2007). Mixed effects models are capable of making accurate descriptions of estimates considering in the results both heterogeneity and heteroscedaticity of biological studies.

Mixed effects models are widely used in the life sciences. Hertog (2007) cited many examples found in preharvest (De Silva and Ball 1997; Usenik et al. 2005; Wei et al. 2002) and postharvest studies (De Ketelaere et al. 2004; De Ketelaere et al. 2006; Ketelaere et al. 2003; Lammertyn et al. 2003).

The objective of this study is to integrate data collected during three years of research, and create a mathematical model based on mixed effects statistical models to predict weight loss of sweetpotatoes during long-term storage.

Figure 3.1: Sweetpotato bins after long-term storage showing different results. a) Sweetpotato bins from modern storage facilities equipped with temperature and relative humidity controllers. b) Sweetpotato bins from storage rooms with poor temperature and relative humidity control.

3.2. Materials and Methods

This study was conducted in controlled environment storage rooms using five sweetpotato varieties. The selected common varieties have similar characteristics, are used primarily for fresh consumption and have orange flesh with a dry matter content of 20% ±2%. The varieties tested were 'Beauregard', 'Carolina Rose', 'Covington', 'Evangeline', and 'Hatteras'. Roots were first cured by the customary method (29.4°C ±2°C and 85% RH for 7 days) in environmentally controlled rooms at the Horticultural Crops Research Station near Clinton, NC. After curing they were taken to the controlled environment room on the campus of North Carolina State University at Raleigh, NC. Eighty kg each per cultivar of sweetpotatoes meeting U.S. No. 1 grade standards were selected (United States Department of Agriculture. Agricultural Marketing Service, Fruit and Vegetable Programs. Fresh Produce Branch 2005).

The roots were stored in two different controlled environment rooms. In the first controlled environment room, the temperature was held constant at 14.1˚C ±0.1˚C while relative humidity (RH) was set at pre-selected values. The RH inside this storage room was sequentially changed in cycles with each cycle lasting 90 days, divided in 30 days' periods. At each period, relative humidity was initially held constant at 85%, and decreased to 75%, and finally to 65%. A total of three cycles and an additional period at 85% RH were necessary to complete 300 days of storage. The upper limit of the RH cycle was 85% because it is the recommended storage RH (Kader 2002). The lower limit was set at 65% in order to avoid very

critical vapor pressure deficit values, which would cause high water stress on the roots (Afek and Kays 2004). Desired humidity levels were maintained using a humidifier (Humidifier 707TW, Herrmidifier, Sanford, NC) and a de-humidifier (Accudry Model AD65USM, Whirlpool, USA). This experiment was repeated two times.

In the second controlled environment room, relative humidity was held constant and the temperature was varied. Temperature inside this room was cycled from 14.4˚C to 21˚C while RH remained constant at 85% ±5%. Each temperature cycle lasted 90 days and was divided into 15 day periods. Each 15 day period had constant temperatures in the following order: 14.4˚C, 17˚C, 14.4˚C, 19˚C, 14.4˚C. The lower limit of the cycle was selected because that is the optimum recommended temperature for the storage of sweetpotatoes; below 14˚C sweetpotato roots are likely to develop chilling injury (Kushman and Pope 1972; Boyette 2009). The upper limit was selected because above 19˚C, sweetpotatoes will initiate a sprouting response depending on the duration in that environment (Afek and Kays 2004). After being held in a non-ideal temperature for 15 days, the temperature was returned to the ideal range (14.4˚C ± 1˚C and 85% ± 5% RH). This experimental sequence was repeated three times.

During both storage conditions described above, the storage temperature and relative humidity as well as the weight of the sweetpotato roots were recorded every hour for 300 days for each experiment repetition. The five sweetpotato varieties

were stored separately in plastic lugs with a total gross weight of approximately 20 kg per lug. They were placed over bending beam load cells strain sensors (TEDEA RL 1042, City of Industry, CA) with a maximum capacity of 30 kg. Each variety was replicated 4 times and the experimental design was a complete randomized block (CRB). As mentioned above, the temperature and relative humidity were recorded hourly using data loggers (Onset HOBO U12, Pocasset, MA.).

Separate statistical models were developed for the data collected in the two different rooms. The experimental design had four replicated units of each of five varieties in each room, in each of three years. Daily mass measurements were aggregated over approximately 300 days, with a total of 6,000 = (4 x 5 x 300) observations per room and per year. The accumulated total is approximately 30,000 observations. The statistical data analysis was conducted using the Statistical Analysis System version 9.3 for Windows (SAS Institute, Cary, NC). Linear mixed models were fit using the MIXED procedure.

3.3. Results and Discussion

The response variable used was weight at time, *t*, relative to initial weights, *w*, at the beginning of the observation period, *w(0)*, expressed as a percentage: $w(t) = 100 \times (w(t) - w(0)) / w(0)$. Where, *w(t)* denotes weight at time, *t*. The model included regression coefficients for variety-specific slopes for decreases in weight over time, (daysold*variety), and regression coefficients for variety-specific response from increased relative humidity, (rh*variety). Random effects were included for each replicate by variety by year combination to allow for correlation between any two measurements made on the same root. To improve the interpretability of the regression coefficients, the response were converted to a percentage change. The estimated regression coefficients for the two roots are given in Table 3.1

Table 3.1: Estimated regression coefficients for relative weight loss of sweetpotatoes stored in a variable relative humidity environment.

Effect	Variety	Estimate (%)	Standard Error (%)	DF	t Value	Pr > |t|
daysold*variety	Beauregard	-0.04036	0.000422	9774	-95.59	<.0001
daysold*variety	CarolinaRose	-0.05644	0.000427	9774	-132.21	<.0001
daysold*variety	Covington	-0.03817	0.000462	9774	-82.55	<.0001
daysold*variety	Evangeline	-0.05955	0.000514	9774	-115.96	<.0001
daysold*variety	Hatteras	-0.08053	0.000461	9774	-174.87	<.0001
rh*variety	Beauregard	0.02888	0.003262	9774	8.85	<.0001
rh*variety	CarolinaRose	0.01787	0.003278	9774	5.45	<.0001
rh*variety	Covington	0.03084	0.003497	9774	8.82	<.0001
rh*variety	Evangeline	0.03386	0.003784	9774	8.95	<.0001
rh*variety	Hatteras	0.05567	0.003491	9774	15.95	<.0001

From these slopes it can be seen that the ‘Hatteras’ variety was losing weight (relative to initial weight) at the greatest rate, at 0.08% weight loss per day. ‘Covington’ and ‘Beauregard’ had the slowest rates. Further, ‘Hatteras’ appeared to benefit the greatest from increased relative humidity, with ‘Carolina Rose’ the least.

The sequential sums of squares in an analysis of variance, Table 3.2, were also obtained using the MIXED procedure. The observed coefficient of determination, defined as the ratio of sums of squares for fixed effects in the model to the total sum of squares, was $R^2 = 0.93 = (1477754+30958)=(1477754+30958+85479+25125)$

Table 3.2: Type 1 ANOVA for relative weight loss of sweetpotatoes stored in a variable relative humidity environment.

Source	DF	Sum of Squares	Mean Square
daysold*variety	5	1477754	295551
rh*variety	5	30958	6191.6
rep*year(variety)	36	85479	2374.4
Residual	9774	25125	2.6

Ratios used in F-tests of equality of rate of weight loss or dependence on humidity across varieties were computed using the rep-by-year-by-variety mean square as the error term. Variation in rate of weight loss across varieties was highly significant ($p<0.0001$), but the test of equality of the effect of relative humidity across varieties was not rejected. Type 3 tests of fixed effects are in Table 3.3.

Table 3.3: Type 3 test of fixed effects for relative weight loss of sweetpotatoes stored in a variable relative humidity environment.

Effect	Numerator DF	Denominator DF	F Value	Pr > F
daysold	1	9774	72045.5	<.0001
daysold*variety	4	9774	1420.58	<.0001
rh	1	9774	464.62	<.0001
rh*variety	4	9774	16.38	<.0001

Note that the observed significance of type III or partial F-tests was even greater, so that there is little doubt about the variety-specific rates of weight loss and dependence on changes in relative humidity. To evaluate differences among the 5 varieties, all 10 pair wise comparisons were conducted for the rates of weight loss, and for the dependence on relative humidity, with results in Table 3.4.

Table 3.4: Estimated variety-specific differences among the slopes of the rate of weight loss of sweetpotatoes stored in a variable relative humidity environment.

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
Beauregard-Carolina Rose	0.01608	0.0006	9774	26.79	<.0001
Beauregard-Covington	-0.00219	0.000626	9774	-3.5	0.0005
Beauregard-Evangeline	0.0192	0.000665	9774	28.87	<.0001
Beauregard-Hatteras	0.04018	0.000625	9774	64.3	<.0001
Carolina Rose-Covington	-0.01827	0.000629	9774	-29.04	<.0001
Carolina Rose-Evangeline	0.003113	0.000668	9774	4.66	<.0001
Carolina Rose-Hatteras	0.02409	0.000628	9774	38.37	<.0001
Covington-Evangeline	0.02139	0.000691	9774	30.95	<.0001
Covington-Hatteras	0.04237	0.000653	9774	64.92	<.0001
Evangeline-Hatteras	0.02098	0.00069	9774	30.42	<.0001

The p-values (unadjusted for multiplicity) suggest that all pair wise comparisons among slopes were significantly different. Pair wise comparisons of the effects of increased relative humidity are listed in Table 3.5.

Table 3.5: Pair wise comparisons of the effects of increased relative humidity on the rate of weight loss of sweetpotatoes stored in a variable relative humidity environment.

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
Beauregard-Carolina Rose	0.01608	0.0006	9774	26.79	<.0001
Beauregard-Covington	-0.00219	0.000626	9774	-3.5	0.0005
Beauregard-Evangeline	0.0192	0.000665	9774	28.87	<.0001
Beauregard-Hatteras	0.04018	0.000625	9774	64.3	<.0001
Carolina Rose-Covington	-0.01827	0.000629	9774	-29.04	<.0001
Carolina Rose-Evangeline	0.003113	0.000668	9774	4.66	<.0001
Carolina Rose-Hatteras	0.02409	0.000628	9774	38.37	<.0001
Covington-Evangeline	0.02139	0.000691	9774	30.95	<.0001
Covington-Hatteras	0.04237	0.000653	9774	64.92	<.0001
Evangeline-Hatteras	0.02098	0.00069	9774	30.42	<.0001

The p-values (unadjusted for multiplicity) indicated that the effect of increasing the relative humidity was plausibly equal for 'Beauregard', 'Covington' and 'Evangeline', but of significantly greatest benefit for 'Hatteras' and least benefit for 'Carolina Rose'.

The resulting statistical model from the analyzed data included fixed effects for the variety-specific effects of time and relative humidity, *RH*, and random effects for the repetition (which is specific to year and variety). This statistical model is represented in equation 3.1.

$$\boldsymbol{w_{ijkt} = \beta_i(t) + \beta_i^{RH}(RH) + R_{ijk} + e_{ijkt}} \qquad (3.1)$$

Where, β is the estimate, i is an index for variety, j is an index for rep, k is an index for year, t is time, and RH is relative humidity. R and e are random rep effects and experimental errors, respectively.

The analysis of temperature proceeded in the same way as for relative humidity. Linear mixed models were again fit to the relative weights at time, t, response using the MIXED procedure of SAS. Regression coefficients for variety-specific rates of weight loss over time, (daysold*variety), and variety-specific effects of temperature (tcdiff*variety) were included along with a random effect for the replicate-by-variety-by-year combination. The estimated regression coefficients are given in Table 3.6.

Table 3.6: Estimated regression coefficients for relative weight loss of sweetpotatoes stored in a variable environmental temperature.

Effect	Variety	Estimate (%)	Standard Error (%)	DF	t Value	Pr > |t|
daysold*variety	Beauregard	-0.02914	0.000257	1.30E+04	-113.24	<.0001
daysold*variety	CarolinaRose	-0.0455	0.000283	1.30E+04	-160.83	<.0001
daysold*variety	Covington	-0.02708	0.000219	1.30E+04	-123.94	<.0001
daysold*variety	Evangeline	-0.03026	0.000298	1.30E+04	-101.71	<.0001
daysold*variety	Hatteras	-0.03707	0.000226	1.30E+04	-164.27	<.0001
tcdiff*variety	Beauregard	-0.01901	0.007148	1.30E+04	-2.66	0.0078
tcdiff*variety	CarolinaRose	-0.09577	0.008108	1.30E+04	-11.81	<.0001
tcdiff*variety	Covington	-0.02756	0.006201	1.30E+04	-4.45	<.0001
tcdiff*variety	Evangeline	-0.04227	0.008401	1.30E+04	-5.03	<.0001
tcdiff*variety	Hatteras	-0.06398	0.006479	1.30E+04	-9.87	<.0001

Similar to the variable relative humidity storage environment data previously analyzed, during variable temperature storage conditions, ‘Covington’ and ‘Beauregard’ experienced the slowest rates of relative weight loss. ‘Carolina Rose’ and ‘Hatteras’ experienced the fastest rates. ‘Carolina Rose’ was the most adversely affected with ‘Beauregard’ and ‘Covington’ the most resistant to increased temperatures.

Sums of squares from an analysis of variance, table 3.7, indicated that most of the variability in relative weight trajectories over time was explained by the fixed linear effects of temperature and variety, with an observed coefficient of determination of $R^2 = 0.92 = (645974 + 3108)/(645974 + 3108 + 43789 + 13211)$.

Table 3.7: Type 1 ANOVA for relative weight loss of sweetpotatoes stored in a variable environmental temperature.

Source	DF	Sum of Squares	Mean Square
daysold*variety	5	645974	129195
tcdiff*variety	5	3107.50	621.50
rep*year(variety)	46	43789	951.92
Residual	12689	13211	1.041168

Ratios used in F-tests of equality of rate of weight loss or dependence on temperature across varieties were computed using the rep-by-year-by-variety mean square as the error term. Variation in rate of weight loss across varieties was highly significant, but the test of equality of the effect of temperature across varieties was not rejected. Type 3 tests of fixed effects are in Table 3.8.

Table 3.8: Type 3 test of fixed effects for relative weight loss of sweetpotatoes stored in a variable environmental temperature.

Effect	Numerator DF	Denominator DF	F Value	Pr > F
daysold	1	1.30E+04	85709.6	<.0001
daysold*variety	4	1.30E+04	828.27	<.0001
tcdiff	1	1.30E+04	230.72	<.0001
tcdiff*variety	4	1.30E+04	17.13	<.0001

Lastly, pair wise comparisons among varieties were conducted for: 1) rate of weight loss and, Table 3.9, 2) susceptibility to temperature, Table 3.10. All pair wise comparisons of rate of weight loss across varieties were significant.

Table 3.9: Estimated variety-specific differences among the slopes of the rate of weight loss of sweetpotatoes stored in a variable environmental temperature.

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
Beauregard-Carolina Rose	0.01636	0.000382	1.30E+04	42.77	<.0001
Beauregard-Covington	-0.00206	0.000338	1.30E+04	-6.11	<.0001
Beauregard-Evangeline	0.001119	0.000393	1.30E+04	2.84	0.0045
Beauregard-Hatteras	0.007924	0.000342	1.30E+04	23.15	<.0001
Carolina Rose-Covington	-0.01842	0.000357	1.30E+04	-51.52	<.0001
Carolina Rose-Evangeline	-0.01524	0.000411	1.30E+04	-37.11	<.0001
Carolina Rose-Hatteras	-0.00843	0.000362	1.30E+04	-23.3	<.0001
Covington-Evangeline	0.003181	0.000369	1.30E+04	8.62	<.0001
Covington-Hatteras	0.009985	0.000314	1.30E+04	31.79	<.0001
Evangeline-Hatteras	0.006805	0.000373	1.30E+04	18.22	<.0001

Table 3.10: Pair wise comparisons of the effects of increased relative humidity on the rate of weight loss of sweetpotatoes stored in a variable environmental temperature.

Label	Estimate	Standard Error	DF	t Value	Pr > |t|
Beauregard-Carolina Rose	0.07675	0.01081	1.30E+04	7.1	<.0001
Beauregard-Covington	0.00855	0.009463	1.30E+04	0.9	0.3663
Beauregard-Evangeline	0.02325	0.01103	1.30E+04	2.11	0.0351
Beauregard-Hatteras	0.04496	0.009648	1.30E+04	4.66	<.0001
Carolina Rose-Covington	-0.0682	0.01021	1.30E+04	-6.68	<.0001
Carolina Rose-Evangeline	-0.0535	0.01168	1.30E+04	-4.58	<.0001
Carolina Rose-Hatteras	-0.03179	0.01038	1.30E+04	-3.06	0.0022
Covington-Evangeline	0.0147	0.01044	1.30E+04	1.41	0.1592
Covington-Hatteras	0.03641	0.008968	1.30E+04	4.06	<.0001
Evangeline-Hatteras	0.02171	0.01061	1.30E+04	2.05	0.0407

Inspection reveals that ‘Beauregard’, ‘Covington’ and ‘Evangeline’ are plausibly equal in their resistance to temperature, with ‘Hatteras’ and ‘Carolina Rose’ exhibiting significantly higher susceptibility to temperature.

The statistical model used to analyze these data included fixed effects for the variety-specific effects of time and temperature, *T*, difference from the recommended level of 14.4, and random effects for the rep (which is specific to year and variety). This statistical model is represented in equation 3.2.

$$\boldsymbol{w_{ijkt} = \beta_i(t) + \beta_i^T(T) + R_{ijk} + e_{ijkt}} \qquad (3.2)$$

Where, β is the estimate, i is an index for variety, j is an index for rep, k is an index for year, t is time, and T is temperature minus 14.4. R and e are random rep effects and experimental errors, respectively.

When using the two models as regression equations, R and e would be negligible. The results from the regression equations would be the weight loss percentage relative to the initial weight of sweetpotatoes stored. It would be necessary to use both regression equations in order to calculate the effects of relative humidity and temperature, then add the two results to determine the total weight loss percentage for the desired storage period.

Other possible models such as the hockey-stick, Malthusian or exponential and quadratic models were fitted for the measured data. None of these models had a better coefficient of determination than the general linear model applied. Measurements and forecasted results, using the statistical models, of the relative weight loss of the different sweetpotato varieties have been shown in individual graphs. The results for the variable relative humidity experiment are in Appendix D, and the results for the variable temperature are in Appendix E.

3.4. Conclusions

This mathematical model based on statistics from data collected during three years, is able to predict weight loss on sweetpotatoes during long-term storage, with an accuracy of above 90% according to the coefficients of determination calculated for the models.

When the studied varieties were exposed to water stress, due to fluctuations in RH, ‘Covington’ and ‘Beauregard’ had the lowest estimated rates of relative weight loss. ‘Carolina Rose’, ‘Evangeline’ and ‘Hatteras’ had higher relative weight loss. When the experimental conditions were at variable environmental temperature, the estimated rates of relative weight loss of the studied varieties from low to high was in the following order: ‘Covington’, ‘Beauregard’, ‘Evangeline’, ‘Hatteras’ and ‘Carolina Rose’. The statistical models proved that the most influential variable in the results of long-term storage is genotype.

Using the regression equations developed during this research study would simplify forecasting the outcome of very complex biological processes that resulted in the shrinkage of sweetpotatoes. Shrink factor or loss rate after harvest of sweetpotatoes has been a continuous concern for growers, packers and researchers. This study would provide a tool to estimate the loss rate after harvest, which would be a very powerful tool for marketing, managing and production planning of sweetpotato.

3.5. References

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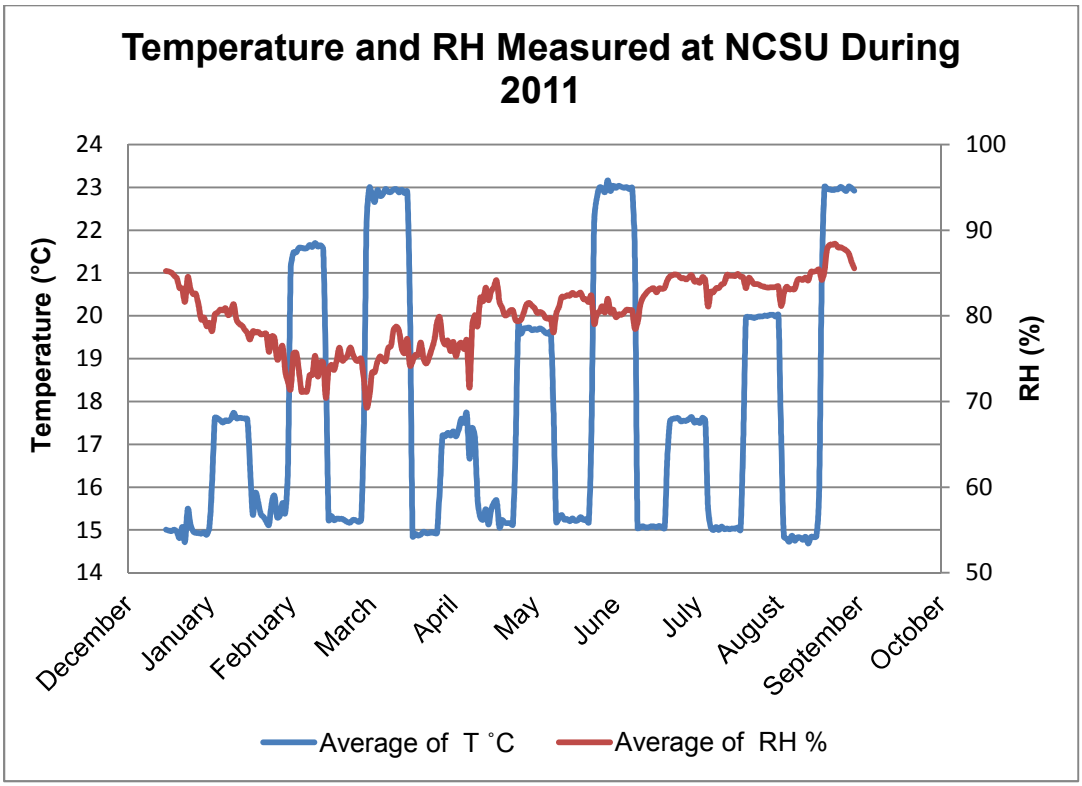
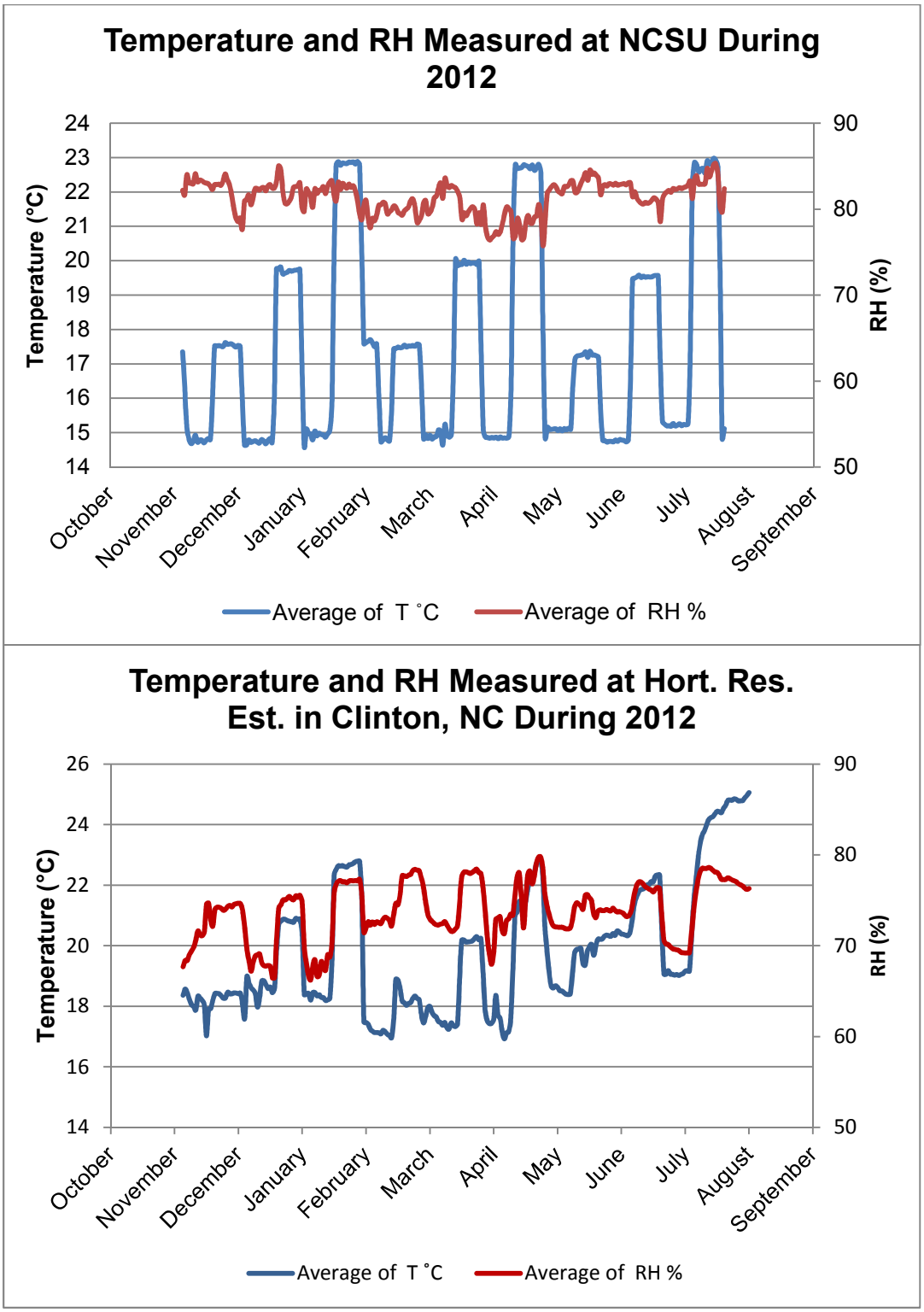
APPENDICES

APPENDIX A

Measured temperature and RH in variable temperature storage at NCSU controlled environment room during 2011 and 2012 and controlled environment storage room at the Horticultural Crops Research Station in Clinton, NC.




Temperature and RH Measured at NCSU During 2012
Temperature (°C)
RH (%)
24
23
22
21
20
19
18
17
16
15
14
90
80
70
60
50
October
November
December
January
February
March
April
May
June
July
August
September
Average of T °C
Average of RH %
Temperature and RH Measured at Hort. Res. Est. in Clinton, NC During 2012
Temperature (°C)
RH (%)
26
24
22
20
18
16
14
90
80
70
60
50
October
November
December
January
February
March
April
May
June
July
August
September
Average of T °C
Average of RH %

APPENDIX B

ANOVA effects and Duncan's groups at level 0.05, for the nutritional characteristics of 'Covington' sweetpotatoes stored under variable storage temperature, treated, and commercial storage conditions, control.

	Dry Matter	Glucose	Sucrose	Fructose	Maltose	Total Sugars	Brix	Starch	β-carotene	Phenolics	Vitamin C	Fat in Chips
ANOVA effects												
Treatments	0.0009	<0.0001	0.19	0.013	0.82	0.29	0.26	0.28	0.0009	0.175	0.0002	0.0049
Months Stored	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Trt*Months	0.05	<0.0001	<0.0001	<0.0001	0.0008	<0.0001	0.61	<0.0001	<0.0001	<0.0001	0.0001	0.17
Duncan grouping												
Treated	a	a	b	a	a	a	a	a	a	a	b	b
Control	a	b	a	a	a	a	a	a	b	b	a	a

Varieties with the same letters are not significantly different at the 0.05 level
p<0.05 values are statistically significative

APPENDIX C

ANOVA effects and Duncan's groups at level 0.05, for the nutritional characteristics of 'Beauregard', 'Carolina Rose', 'Covington', 'Evangeline', and 'Hatteras' sweetpotatoes stored under variable storage temperature conditions.

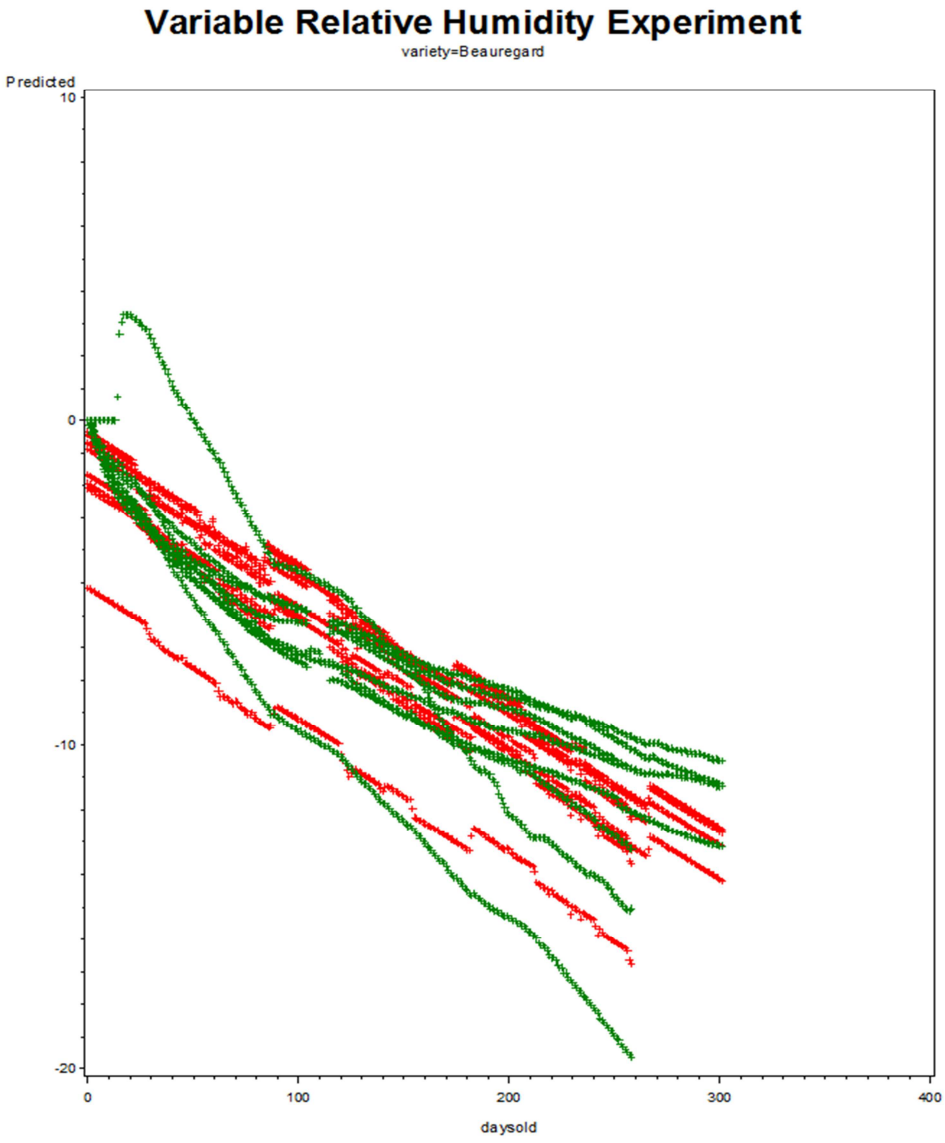
	Density	Dry Matter	Glucose	Sucrose	Fructose	Maltose	Total Sugars	Brix	Starch	β-carotene	Phenolics	Vitamin C	Fat in Chips
ANOVA effects													
Variety	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0003	<0.0001
Months Stored	<0.0001	<0.0001	0.12	0.0004	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Var*Months	0.05	0.31	<0.0001	<0.0001	0.0004	0.13	0.0009	0.0005	<0.0001	<0.0001	<0.0001	<0.0001	0.0008
Duncan grouping													
Beauregard	bc	c	b	d	b	c	bc	e	a	d	c	a	c
Carolina Rose	ab	c	c	c	c	c	bc	c	a	b	d	b	b
Covington	d	bc	d	a	c	a	a	b	c	d	c	b	a
Evangeline	a	a	e	b	d	c	c	a	b	a	a	a	d
Hatteras	c	b	a	e	a	b	b	d	a	c	b	a	a

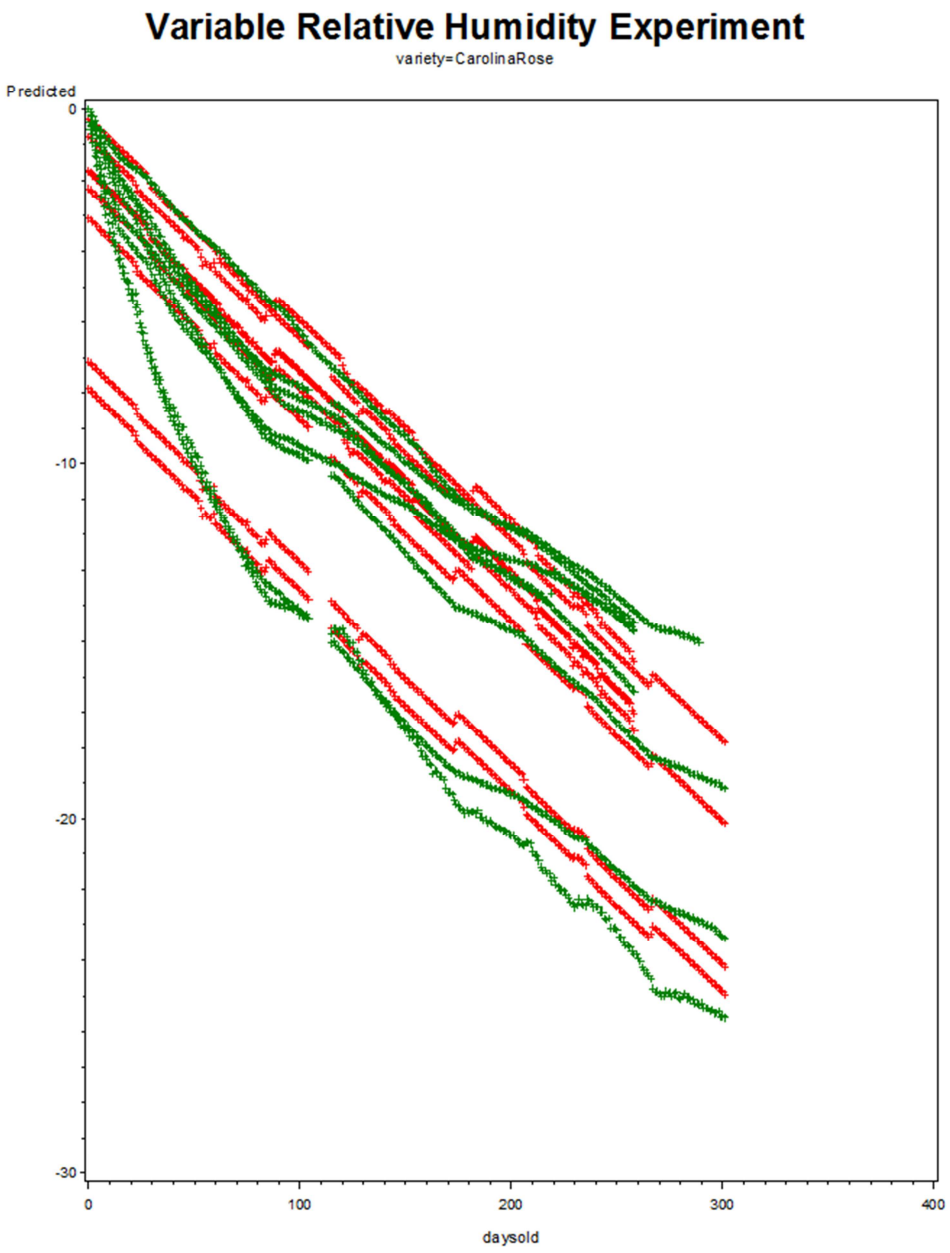
Varieties with the same letters are not significantly different at the 0.05 level

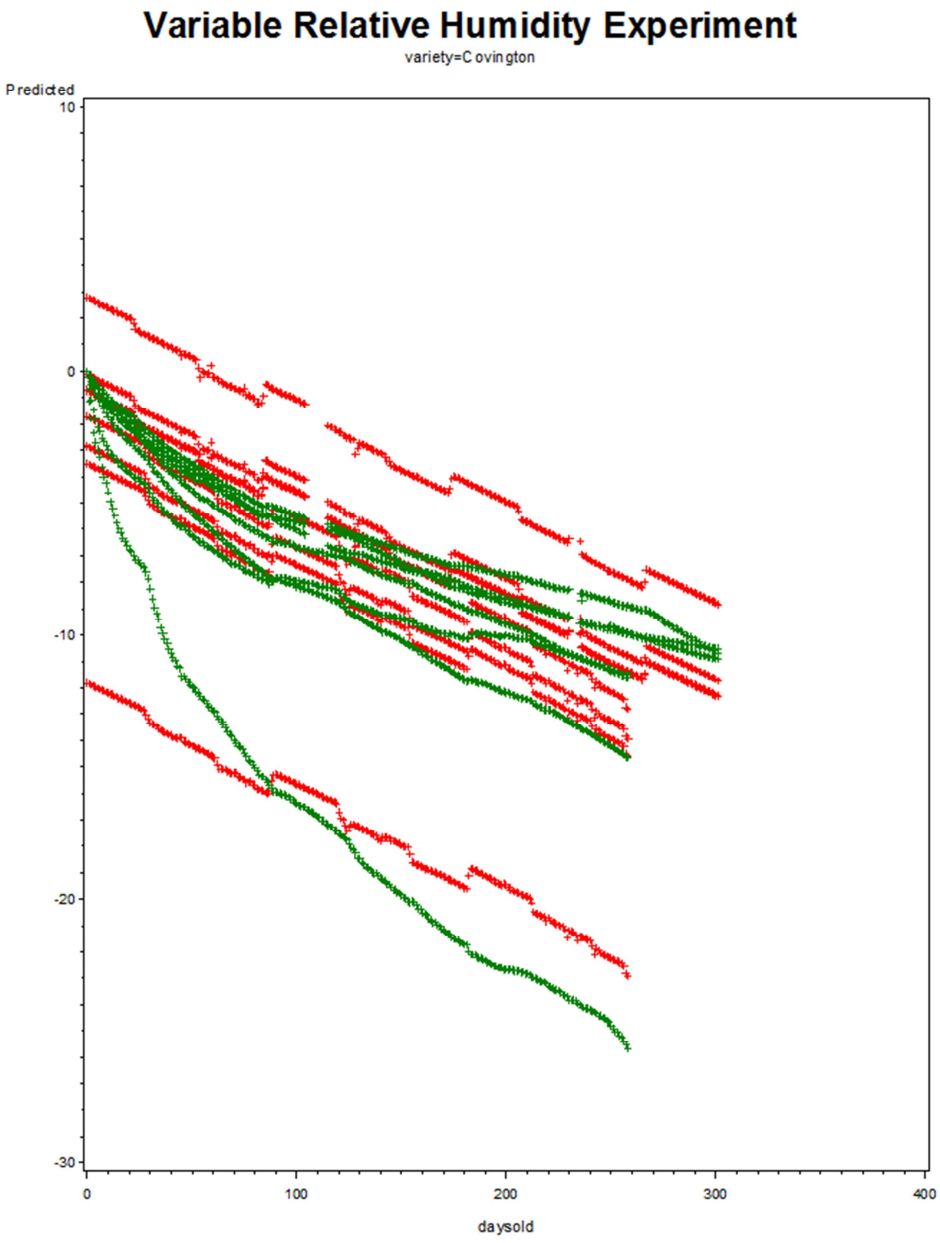
p<0.05 values are statistically significative

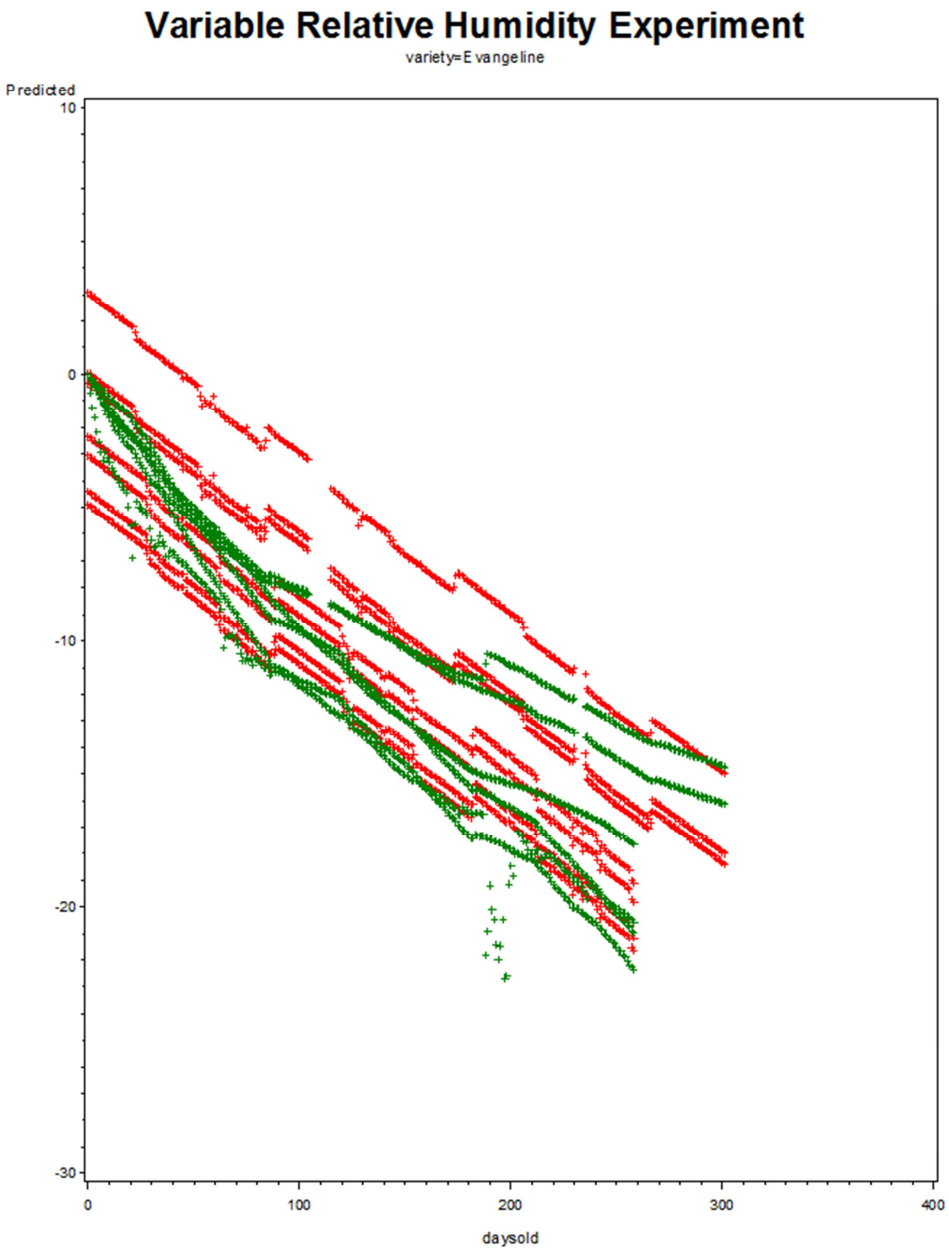
APPENDIX D

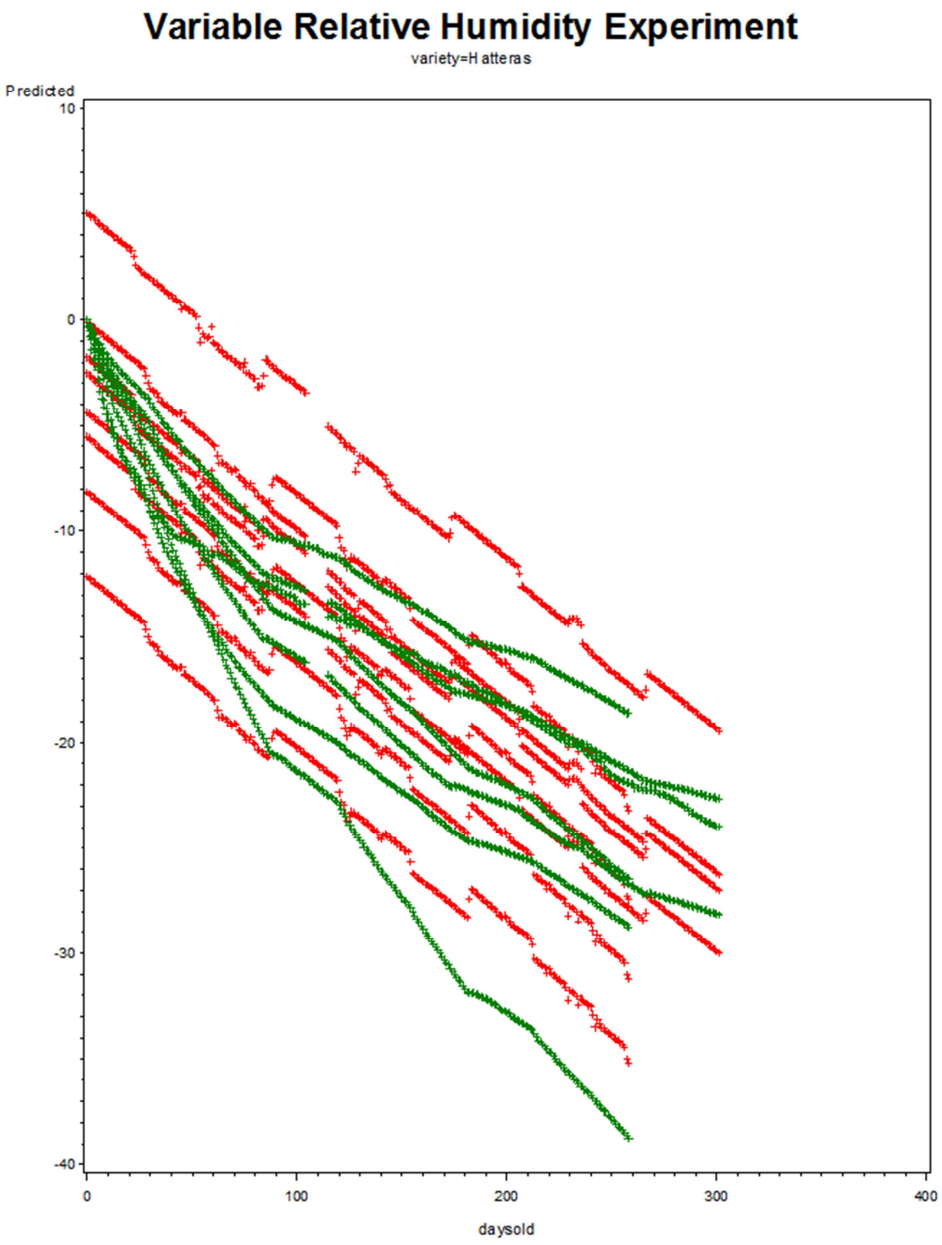
Measurements and forecasted results, using the statistical models, of the relative weight loss of the different sweetpotato for the variable relative humidity experiment.




Variable Relative Humidity Experiment
variety=CarolinaRose
Predicted
0
-10
-20
-30
0
100
200
300
400
daysold

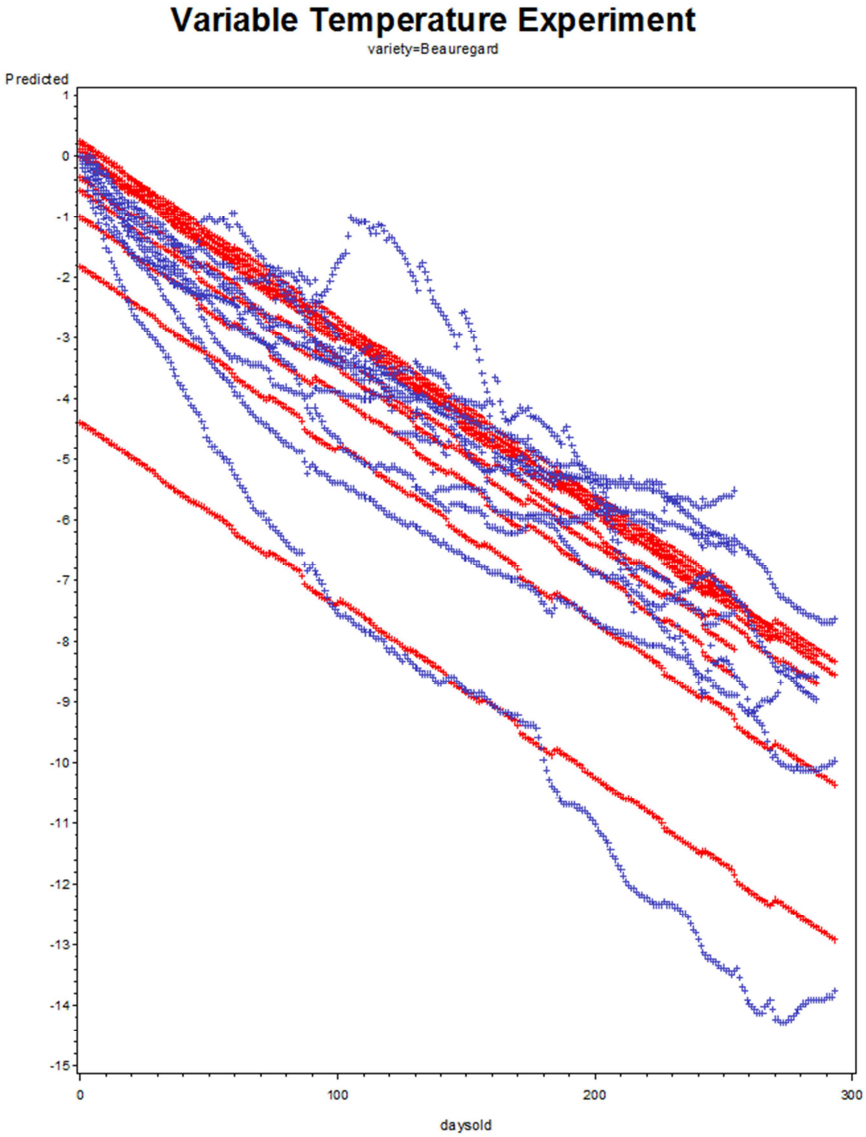

Variable Relative Humidity Experiment
variety=Covington
Predicted
10
0
-10
-20
-30
0
100
200
300
400
daysold

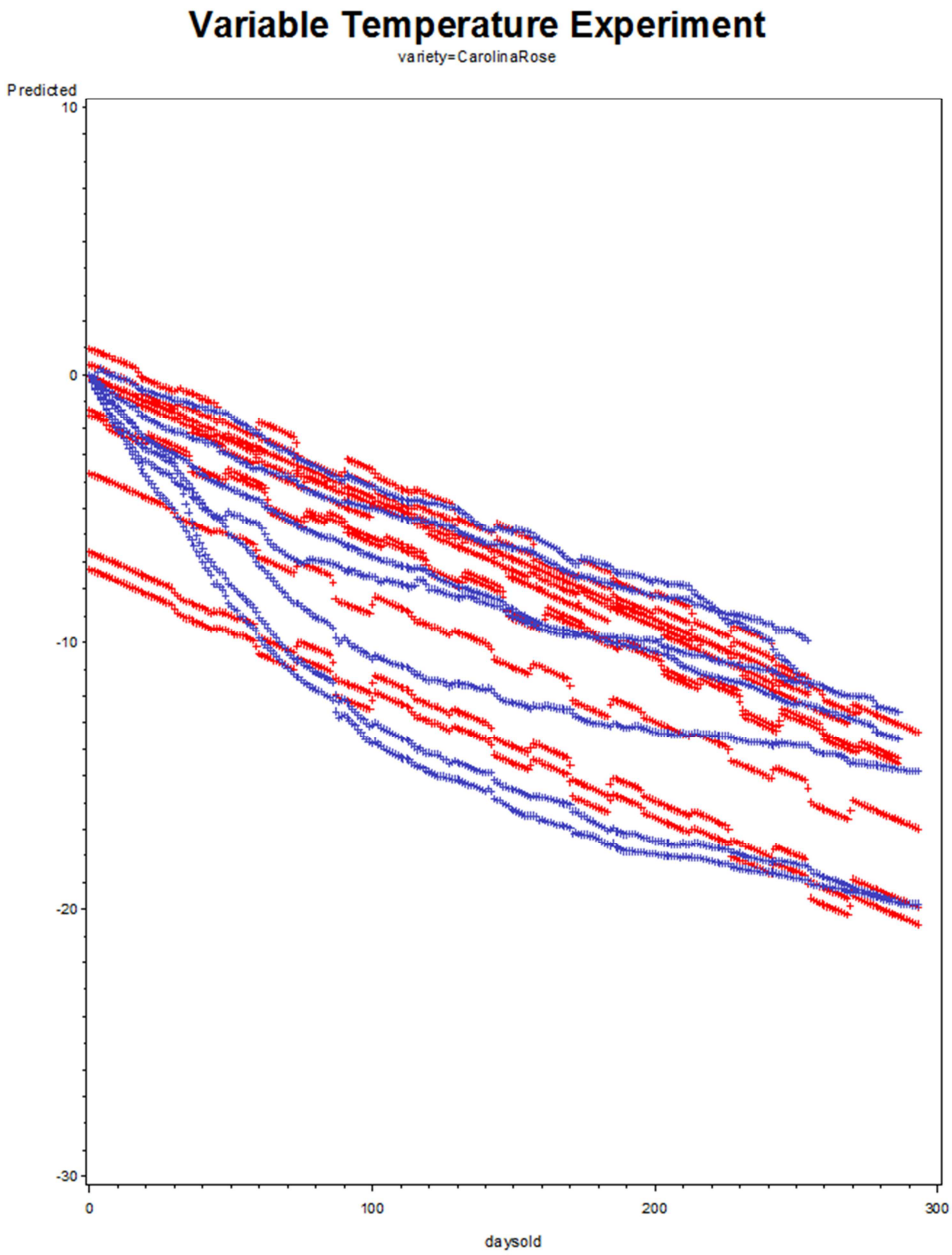

Variable Relative Humidity Experiment
variety=Evangeline
Predicted
10
0
-10
-20
-30
0
100
200
300
400
daysold

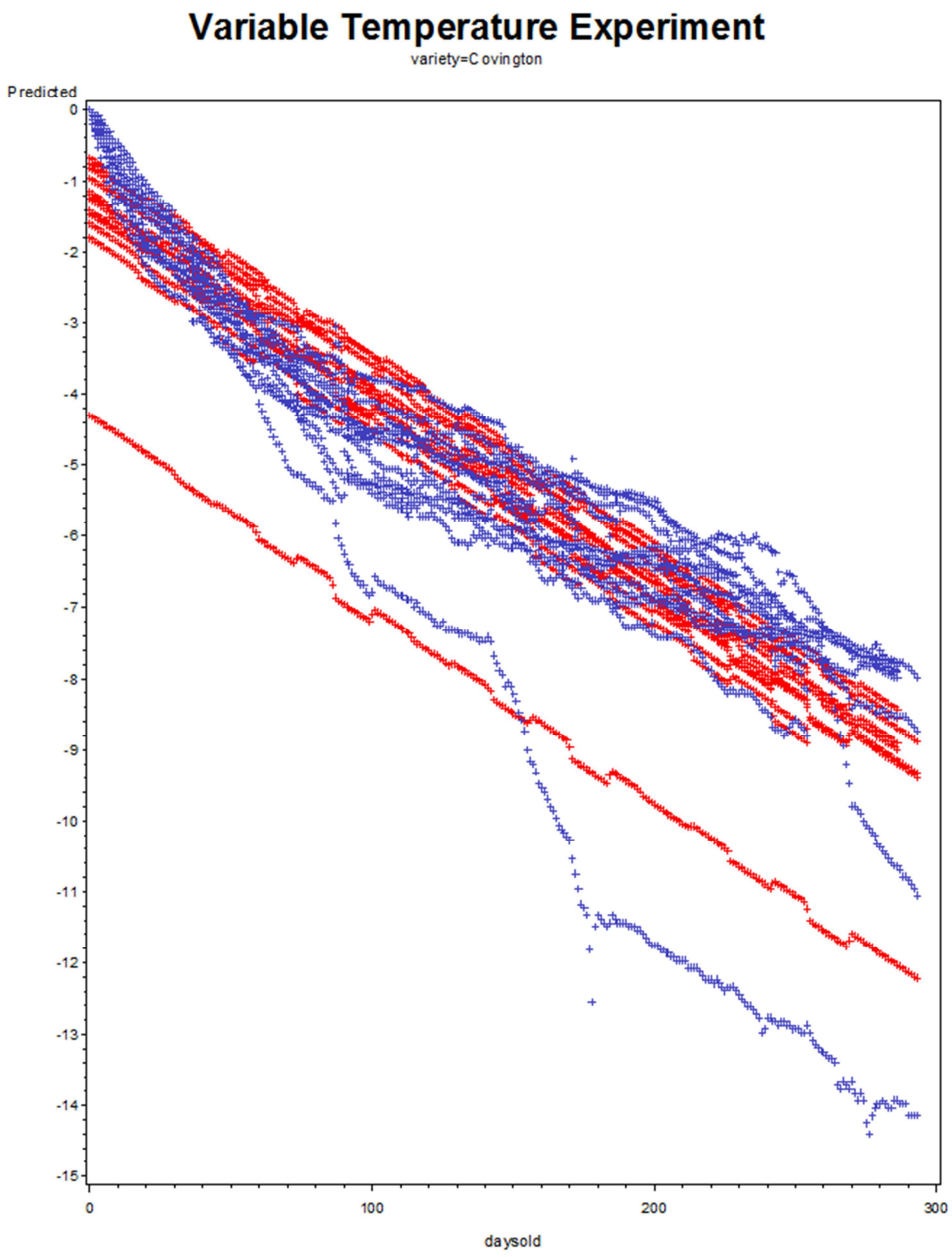

Variable Relative Humidity Experiment
variety=Hatteras
Predicted
10
0
-10
-20
-30
-40
0
100
200
300
400
daysold

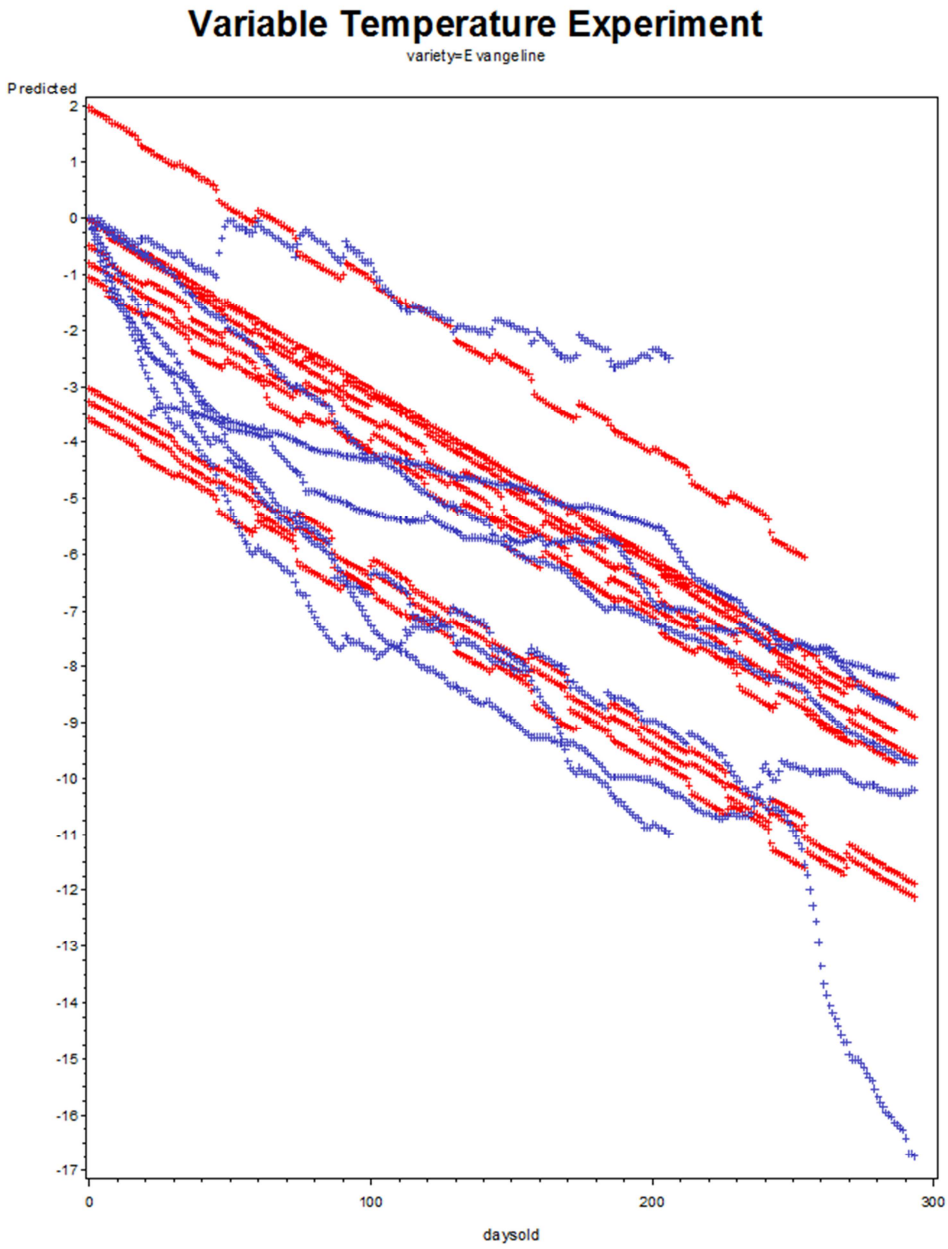
APPENDIX E

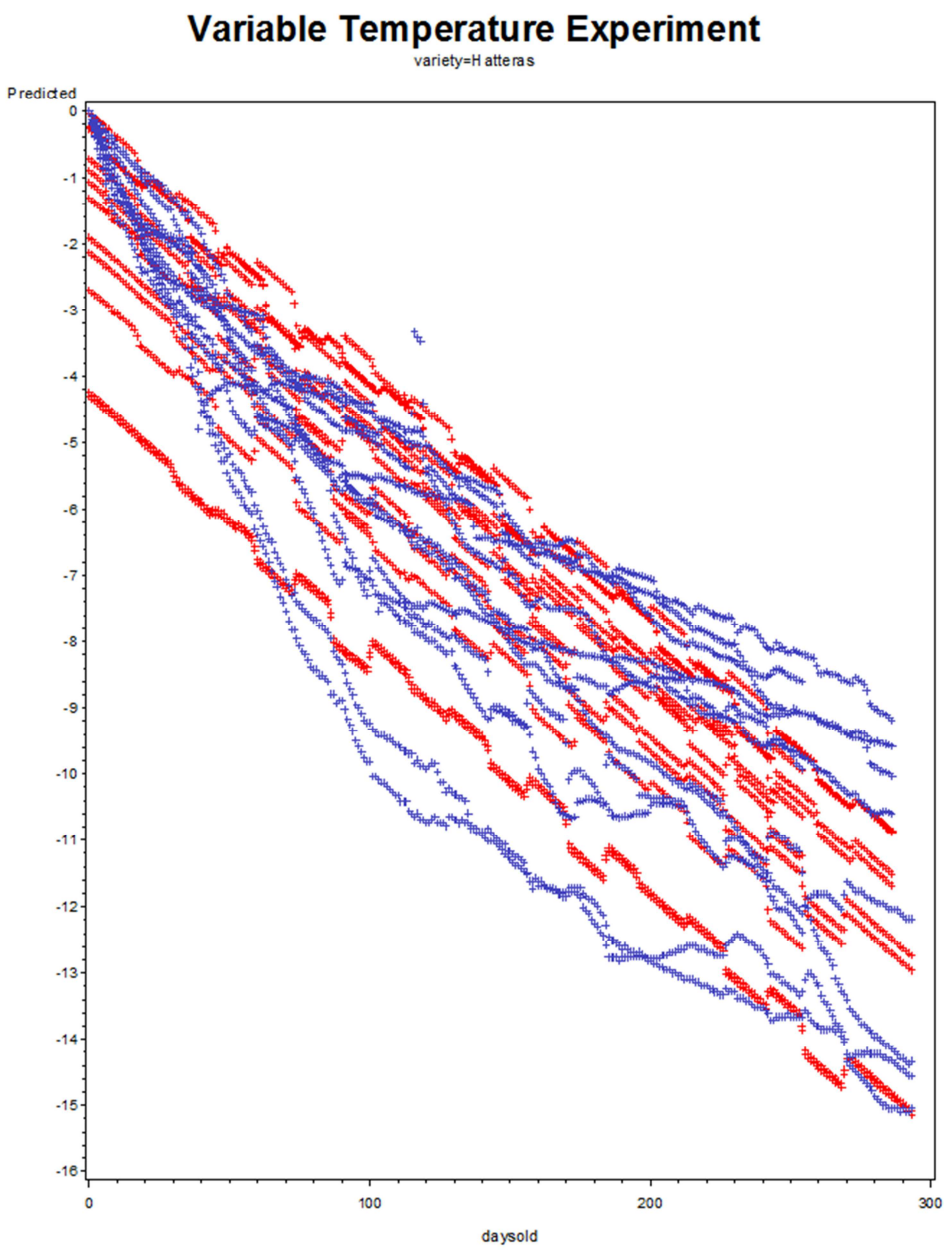
Measurements and forecasted results, using the statistical models, of the relative weight loss of the different sweetpotato for the variable temperature experiment.




Variable Temperature Experiment
variety=CarolinaRose
Predicted
10
0
-10
-20
-30
0
100
200
300
daysold


Variable Temperature Experiment
variety=Covington
Predicted
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
0
100
200
300
daysold


Variable Temperature Experiment
variety=Evangeline
Predicted
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
0
100
200
300
daysold


Variable Temperature Experiment
variety=Hatteras
Predicted
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
0
100
200
300
daysold