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Morphological and physiological characterization of sweetpotato roots after skinning.

By

Nestor Javier Bonilla Bird

A Dissertation
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
in Horticulture
in the Department of Plant and Soil Science

Mississippi State, Mississippi

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2015

Morphological and physiological characterization of sweetpotato roots after skinning.

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Sweetpotato is an important staple crop, and a supplementary source of nutrients; minerals, carbohydrates, and vitamins, for the food industry. Quality of sweetpotatoes depends on cultivar, preharvest management practices, and harvest equipment causing skinning. Information on morph-physiological characteristics of storage roots is needed for preharvest management decisions, cultivar selection, and application of harvest aids and harvesting procedures for postharvest storage durability of sweetpotatoes. Also, devices to measure skinning properties of storage roots are needed. This research was conducted to measure skin toughness of various sweetpotato cultivars. The number of skin layers was determined using fluorescent microscopy, and lignin content was determined with the Near Infrared System. Preharvest cultural practices, such as devining to enhance skin set and lignin content, were applied 1, 3, 7 days preharvest, and Ethephon at the rate of 1.68 $ha^{-}$and 0.84 kg ha^{-1} applied at 1, 3, and 7 days preharvest.

In addition, curing to enhance skin healing and lignin content was evaluated. This research was conducted in the field and in the greenhouse environments.

The force gauge and the torquometer were the most accurate and precise devices to measure the force needed to break the skin of the various sweetpotato cultivars. The cultivars, “L07-6R”, “L07-146”, and “Beauregard-14” had the toughest skin compared to the other cultivars. However, “Covington” and “Hatteras” had the highest lignin content. Fluorescent microscopy showed that the cultivars “L07-6R” and “L07-146” had 12 and 10 cell layers, respectively, and the treatment of Ethephon at 1.68 Kg·ha-1 3 days and 7 days before harvest resulted in the highest lignin content in the skin. Divining 3 days preharvest, and applying Ethephon at 0.84 kg·ha-1 at 1day and 3days preharvest resulted in the highest lignin content. In addition, the treatments with Ethephon at 1.68 Kg·ha-1 applied at 3 days and 7 days preharvest resulted in the hardest skin as indicated by torquometer and the force gauge.

Curing for 7 days resulted in higher lignin content compared to the others pretreatments. When wounded and cured for 7 days, the healing process was enhanced greatly, resulting in rapid skin set of sweetpotato storage roots.

DEDICATION

To my wife, Fany Montenegro Valenzuela, for her patience and loving care during my graduate level studies at Mississippi State University. To my daughters, Elia and Fanny, for their comprehension and sacrifices. To my son, Nestor, for his hard work studying all this time in the honor group at Starkville's public schools. To all my family and friends for their support to see my studies culminated.

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TABLE OF CONTENTS

DEDICATION ii

ACKNOWLEDGEMENTS iii

LIST OF TABLES vii

LIST OF FIGURES x

CHAPTER

I. INTRODUCTION 1

II. LITERATURE REVIEW 7

Skin characteristics and resistance to skinning 7
Skin adhesion / Skinning 9
Ethylene / Devining on skinning 10
Wound healing 11
Harvest and Curing 13
Mechanical properties of the plant cell wall 14

III. MATERIALS AND METHODS 16

Experiment 1. Determine the morphological differences and the breaking point of the periderm of sweetpotato storage roots with four mechanical testers. 16
Objectives: 16
Suitability of four instruments to measure shear and tensile resistance to fracture 16
Shear and tensile force determination. 18
Experiment II. Anatomical characterization and lignin content in sweetpotato storage roots. 20
Objective: 20
Experiment III. Evaluating preharvest cultural practices to enhance the sweetpotato storage roots skin set. 22
Objective 22
Experiment IV. Evaluate changes in skin characteristics due to curing and without curing of sweetpotato storage roots 23
Objective 23

Experiment V. Evaluated anatomical changes during the wound healing process with and without curing. 24
Objective 24

IV. RESULTS AND DISCUSSION 26

Experiment 1. Determine the morphological differences and the breaking point of the periderm of sweetpotato storage roots with four mechanical testers. 26
Experiment II. Anatomical characterization and lignin content in sweetpotato storage roots 38
Experiment III. Evaluating preharvest cultural practices to enhance sweetpotato storage root skin set. 58
Experiment IV. Evaluating changes in skin characteristics due to curing and without curing of sweetpotato storage roots. 68
Experiment V. Evaluation of anatomical changes during the wound healing process with and without curing. 72

V. SUMMARY AND CONCLUSION 83

REFERENCES 86

LIST OF TABLES

4.1 Shear and Tensile force of sweetpotato periderm, cultivar "Beauregard-14" as measured with the Torquometer..........................27

4.2 Shear and Tensile force of sweetpotato periderm, cultivar "Beauregard-14" as measured with the Force gauge...........................27

4.3 Shear and the tensile force of the skin of sweetpotato storage roots as determined by the force gauge at harvest. 29

4.4 Pressure at which water of the skinometer induced within 20 seconds skin fracture of the storage sweetpotato root at harvest.......................31

4.5 Shear and the tensile force required to break the skin of sweetpotato storage roots of seven cultivars at harvest as determined by the torquometer. 32

4.6 Shear and the tensile force required to break the skin of sweetpotato storage roots of seven cultivars at harvest as determined by the Instrom. 34

4.7 Statistical descriptive parameters comparing the Force gauge and the Torquometer used to measure the force of storage roots of seven cultivars at harvest. 36

4.8 A number of cell layers in the phellem, phellogen, and phelloderm and total number of cell layers in the periderm of eight sweetpotato cultivars as determined by fluorescence microscopy...........................40

4.9 Periderm components of sweetpotato storage root of eight cultivars at harvest as determined by fluorescent microscopy 43

4.10 Lignin, calcium, ash, and dry matter content in the skin of sweetpotato storage roots of seven cultivars as determined by NIR^{z} at harvest..46

4.11 Cell heigth, cell wall thicknes, and relative skin densityof sweetpotato storage root of six cultivars at harvest. 48

4.12 Correlation between the density of cells walls of the periderm with structural and chemical components of sweetpotato storage roots of six cultivars at harvest. 49

4.13 Correlation between force needed with the force gauge to fracture the skin and the structural and chemical components of sweetpotato storage root of six cultivars at harvest. 51

4.14 Correlation between pressures needed to fracture the skin with the skinometer and the structural and chemical components of sweetpotato storage root of six cultivars at harvest. 53

4.15 Correlation between torques needed to fracture the skin with the torquometer and the structural and chemical components of sweetpotato storage of six cultivars at harvest....55

4.16 Correlation between pressures needed to fracture the skin with the Instrom and the structural and chemical components of sweetpotato storage root of six cultivars at harvest. 57

4.17 The effect of preharvest treatments on lignin content of cultivar "Beauregard-14", sweetpotato storage roots observed by fluorescent microscope at harvest. 59

4.18 The effect of preharvest treatments on lignin content of the cultivar "Beauregard-14", sweetpotato storage roots observed by NIR at harvest. 61

4.19 The effect of preharvest treatments on tensile stress plus the shear stress measured with the torquometer on the skin of cultivar "Beauregard-14", sweetpotato storage roots at harvest. 63

4.20 The effect of pretreatments on tensile stress plus the shear stress measured with the force gauge on the skin of cultivar "Beauregard-14", sweetpotato storage roots at harvest. 64

4.21 The effect of preharvest treatments on cell wall density observed with the fluorescent microscopy on the skin of sweetpotato cultivar "Beauregard-14", storage roots at harvest. 66

4.22 Effect of curing on the lignin content observed with the fluorescent microscopy in cultivar "Beauregard-14". 69

4.23 Skin resistance to shear and tensile forces in sweetpotato storage roots at harvest, after curing and non-curing for seven days as determined by the torquometer. 70

4.24 Skin resistance in sweetpotato roots to shear and tensile force at harvest, non-curing and curing for seven days as determined by the force gauge. 71

4.25 Effect of curing on wound healing and lignin content of three sweetpotato cultivars determined by the fluorescent microscopy. 73

4.26 Effect of curing during different period over the physical parameters of the cell skin storage sweetpotato roots in three cultivars.....................75

4.27 Cell length, cell thickness, and skin density of skin cell as influenced by curing. 82

LIST OF FIGURES

4.1 Microphotograph showing the distribution of the tissues, which compose the periderm called skin of the storage root of sweetpotato. 26

4.2 Tensile and shear stress determined of the periderm of sweetpotato storage roots with the Torquometer. 28

4.3 Tensile and shear forces of the periderm of sweetpotato storage roots determined with the force gauge. 30

4.4 Photographs of sweetpotato storage roots showing scars made after measuring the shear and tensile stress of the skin by four instruments. 35

4.5 Microphotographs showing periderm characteristics of the storage roots of eight cultivars as determined by fluorescence microscopy at harvest. 41

4.6 Microphotographs of sweetpotato root skin tissue showing different phases of curing and healing taken with the fluorescent light with the confocal microscopy to the periderm of storage roots of sweetpotato, cultivar “L07-6R”. 77

4.7 Microphotographs of sweetpotato root skin tissue showing different phases of curing and healing process takes with the fluorescent light with the confocal microscopy into the periderm of the storage roots of sweetpotato “L07-146”. 79

4.8 Microphotographs of sweetpotato root skin tissue showing different phases of curing and healing process takes with the fluorescent light with the confocal microscopy into the periderm of the storage roots of sweetpotato cultivar “Beauregard-14”. 81

CHAPTER I

INTRODUCTION

Sweetpotato (*Ipomoea batatas* [L.] Lam.) is a dicotyledonous plant that belongs to the family Convolvulaceae (Chaffey, 2008; Austin, 1988). "Ipomoea" is a Greek word which has the meaning as "bind weed". The species name "batatas" was the native name. The Spanish started the consumption of sweetpotatoes and other crops since they arrived at the new word, Caribbean Islands and Central America, and brought this crop to Europe and Asia. It was also called at that time "camote" as the Mayan's language and in the Nahuatl languages "Camotli" (Roullier et al., 2012; Keesler, 2011).

Vavilov (1926) published the "Studies on the Origin of Cultivated Plants". He based his theories in this manuscript and described the origins of cultivated plants; he recognized eight centers of origin where the major crops were domesticated; one of them with the most diverse in new crops was Mesoamerica. It is a baste region in the tropical zone from southern Mexico to all countries in Central America where sweetpotatoes were domesticated at least 5,000 years ago. In South America, on the south-central coast of Peru, sweetpotato were found from ancient tombs and burial sites from 8000 BC (Ugent and Peterson, 1988; Keesler, 2011; Roullier et al., 2012).

According to the Department of Statistic of the Food and Agriculture Organization (FAO), world production in 2004 was 127 million tons. The strongest production was from China, 105 million tons, most of the crop was used for animal feed.

USA production for the same period was 700,000 tons. For 2010, China decreased to 74 million tons, and USA increased to 1,080 million tons. From that production, Mississippi contributed 18 % (USDA, 2013).

The most important loss in quality appearance of sweetpotato storage roots in the fresh market is due to skinning. Skinning occurs when abrasive forces cause a wound in the periderm or skin. The Periderm is located at the surface area of the storage root, and is composed of three types of tissues: phellem, phellogen, and phelloderm.

External forces that fracture the meristematic cell layer called phellogen or meristematic cork affect the periderm. It is located between the phellem and phelloderm, resulting in the separation of the phellem from the phelloderm (Lulai, 2002 to 2008; Villavicencio et al., 2007). This surface scratch increases the risk of pathogen infection, water loss, and skin shriveling, but also renders the roots visually unappealing (Walter, 1983; Sumner, 1984; and 1990; Kum, 1991; Halstead and Page, 1992). The scratch and wounded and dark areas can easily be confused with symptoms of surface rot or Fusarium root rot (Clark, 1992; Blankenship and Boyette, 2002; Clark et al., 2013). Skinning wounds are the entrance for microorganism, which may cause severe loss. However, the occurrence of postharvest infections increases by skinning and the presence of spores, microorganism in the dust from the field, the lack of cleaned containers, and unclean storage buildings, and the lack of good practices in the processing chain of sweetpotato roots (Karuri, 1993; Harrison, 2001; Villavicencio et al.,, 2007; Clark, 2013).

Sweetpotato periderm is the first line of insulation against pathogens and moisture loss. Some chemical components of the periderm such as resin compounds, lignin, and phenolic are stored in the periderm and are considered a defensive barrier against attack

by microorganism that cause diseases (Harrison, 2003). These products were extracted from the skin, and then used to observe the inhibitory power against microorganism known for their attack on the sweetpotato roots. The pathogens tested were *Fusarium oxysporum* Schlecht. Emend. Snyder &Hansen., *Fusarium solani* f.sp. pisi W.C. Snyder &H.N. Hansen*, Lasiodiplodia theobromae* Patouillard*, and Rhizopus stolonifer.* In addition, these chemicals compounds have been used to investigate their inhibitory power on the germination of some seed weed, and were found to inhibit seed germination of nine weed species (Harrison, 2003).

Therefore, it is necessary to decrease wounds during mechanical harvest with plows, and diggers, and the handling in packing line and in shipping sweetpotatoes to market. There is a need for good manufacturing practices (Summer, 1984; Legendre, 2015). Recommendations for postharvest handling of storage roots of sweetpotatoes have been reported (Adams, 1986; Arif, 2013; Grace, 2014). In large-scale production, transportation and trade operation of sweetpotatoes have been changed to minimize scratches and wounding (Villavicencio et al., 2007).

Since the phellem hardenes by deposition of lignin and suberin, the next fragile plane in the periderm is the phellogen. Due to its meristematic nature, the phellogen lack of cell wall firmness. Therefore, skin adhesion or resistance to skinning determines the capability of the phellogen cell wall to resist fracture. Adhesion varies among cultivars, as is influenced by environmental conditions and cultural practices, which affect skin characteristics and consequently the bond between cell layers (VanOirschot, 2003; Rees, 2003; Lulai, 2004; Villavicencio, 2007). When the soil at harvest is too dry, this increase the menace of skinning, because hard, fry chunks of soil cause greater injury than loose

soil. In addition, high temperature during storage root growth increases skin lignification and skin adhesion (Villavicencio, 2007). Another aspect to consider is that sweetpotato storage roots do not mature like a fruit. They continue to growth as long as they are in the soil and the growing conditions allow them to continue growing (Villordon, 2011). Sweetpotatoes need to be harvested early before the vines are destroyed by frost or the soil temperature drops below 13 ºC (Purcell, 1985).

Harvesting involves hard labor and is very expensive. To reduce labor costs, devinning equipment was developed to eliminate hand vine separation and to increase harvesting efficiency (Smith and Wright, 1994); Schultheis et al., 2000). These tools also decreases skinning of storage roots by decreasing the management of trying to separate the root from the vines at harvest (LaBonte and Wright, 1993; Wright, 1994). Devining or taking off the vines defoliation 4-10 days prior to harvest as well as the use of ethylene products improves skin bond and decreases damages at harvest (O'Brien, 1969; LaBonte and Wright, 1993; Schultheis et al., 2000; Rees, 2008). Curing promptly after harvest for 7 days at 85% relative humidity and 29 ^{0}C, also allows periderm tissues to sticking together, reducing skinning damage during washing and packing for commercial sales (Walter and Schadel, 1983; Blankenship and Boyette, 2002).

Once excoriating has occurred at harvest, it is important to speed up the healing process by curing (Walter, 1990) curing promotes restoration of the wounded area in the periderm, and protect the storage root against microorganism infection and moisture loss (Rees, et al., 2003). The healing process begins with the desiccation of cell wall located at the outer layer of the damaged area, followed by lignification of the cells walls of the first cell layers (Walter and Shadel, 1983; Villavicencio et al., 2007; Wang, 2013). This

lignified cell layers become the protecting blockade against pathogen infections, and moisture loss in the recently formed periderm (Walter and Schadel, 1983). Wound healing is finalized with the formation of the new cell layer below the lignified cell layers (Brown, 1978). Ethylene has a crucial leading role in wound healing by triggering the development of lignification and periderm conformation (Randle and Woodson, 1986; Amand and Randle, 1991). Exposing the wounded roots to high curing temperature promotes metabolic activity that promotes periderm formation (Summer, 1987; VanOirschot, 2003; Rees, 2008). Therefore, roots need to be exposed to curing condition immediately after harvest to reduce weight loss and microbial decay and maintain an acceptable marketing quality.

It is necessary to determine periderm hardiness, resistance to peeling, and resistance to skinning of the storage roots of sweetpotato in terms of skin set and periderm maturation. There are two kind of stresses involved in the skinning process that have to be determined: tensile stress and shear stress. Tensile stress is when equal and opposite forces are applied in a 90-degree angle to the plane or surface affected. Shear stress is a state where the stress is parallel or horizontally to the plane or surface of the material (Rees, 2003).

Many researchers have developed tools and techniques for measuring tensile and shear force of the surface of the skin of fruits, and roots. Such tools include the Instron, the torquometer, the steel plunger, the penetrometer, the water jet, and the force gauge (Gould, et al., 1995; Gorzelany and Puchalski, 2000; Rees et al., 2002; Villavicencio et al., 2003).

Skin hardiness is associated with lignin content of the periderm. Lignin content in plants or plant organs can be determined quantitatively with gravimetric or spectrophotometric analysis with disadvantages, which are; relatively large sample size os required, techniques are time-consuming, and it is difficult to find appropriate calibration standard or spectrophotometric methods (VanZyl, 1978; Martens, 2002; Camarero, et al., 2005). One method, the use of the emission of the fluorescent light after the phenolic ring excitation of the lignin, which is captured by the camera or lens of the confocal scanning microscopy, allow the scanning of the picture to quantify relative lignin content. The latest method developed is near infrared spectroscopy (NIR) to determine lignin content (Mattes, 2012).

In the USA, loss on sweetpotato storage roots after harvest, are 20-25% during curing and storage, 5-15% during transport, and 10-15% after sweetpotato reach the consumer (Lewthwaite, 2012).

The objectives of this study were to: (1) determine the suitability of four instruments (Skinometer, Force gauge, Torquometer, and Instron) to measure skin toughness on periderm resistance in sweetpotato storage roots, and compare the resistance of the periderm with skin thickness differences among cultivar, (2) determine periderm anatomical characteristics and chemical in the periderm of sweetpotato storage roots in seven cultivars, and associate periderm anatomical and chemical characteristics with skinning resistance, (3) determine the effect of preharvest strategies on skinning resistance in sweetpotato storage roots, (4) determine anatomical and chemical skin characteristics due to curing, and (5) characterize the healing process with and without curing.

CHAPTER II

LITERATURE REVIEW

Skin characteristics and resistance to skinning

It is very important to understand the role of the periderm as a barrier in sweetpotato storage roots. In addition, the importance and the role of some chemical components, such as lignin, are actively involved in shaping some notable features in the skin of the root. Sweetpotato roots are injured during harvest and postharvest handling. These wounds facilitate weight loss, wrinkling of the root surface, and increased susceptibility to pathogen attack and deterioration in quality marketing (Sumner 1984; Walter and Schadel, 1980; Kum, 1991; Villavicencio et al., 2007).

The sensory quality for agricultural products is judged by their external appearance, taste and texture. There are three types of factors that influence the attitude and behavior of a product acceptance by consumers; appreciation, feeling and purchase intentions. These are related to the properties of food and other products (Halstead and Page, 1992).

Consequently, it is crucial to decrease wounding during mechanical harvest with plows, and diggers, and during the handling involved in packing line and in shipping sweetpotatoes to market place (Summer, 1984).

The skin is a complex system with different components. The skin has three elements to consider as follows; anatomical, biochemical, and physiological. It is very

important to look these elements as a complex system, with many interaction effects to understand how the skin elements work. First, the meristem is formed by active growing cells. In dicotyledons, the meristem is at the shoot tip and the cambium in the stem and root tips. Periderm or skin is a protective tissue of sweetpotato storage roots, which belongs to the cambium and usually consists of only one line of stem cells that are actively dividing to give rise to new cells, and this dynamic growth of this tissue is stimulated where the meristem is located. The cambium has the ability to produce new cells at sites where there has been injury, allowing healing of the wounded area. In the roots, the cambium is responsible for promoting growth in length, thickness and width. The cells of the cambium layer grows radially inward in tissues of stems and roots. It is called the cork cambium. Cork cambium contains greater amounts of suberin in their walls, thus, acting as an insulating layer, which make up the phellem (Randle and Woodson, 1986).

Suberization reduces cell capacities to exchange gases, water and nutrients, and consequently, cells die. Cells pushed from the cork cambium to the inside are called phelloderm, and these cannot be suberized and remain alive, they can exchange gases and obtain nutrients from other tissues (Makimoto and Asahi, 1981; Smith, et al., 1994; Arif, 2013).

Chemical components of the skin sweetpotato root are like an obstacle to penetration of bacterial or fungal diseases, research was conducted to determine the effect of the chemical components on diseases control. Sweetpotato periderm chemical components were tested for their inhibition and control effect on the establishment of four fungi that affect sweetpotato skin roots: *Fusarium oxysporum* Schlecht, f. sp. *batatas*

(Wollenw) Snyd. & Hans, and F. *solani* (Sacc.) Mart., which cause root and stem infections in the field; and, *Rhizopus stolonifer* (Ehr. ex Fr.) Lind, and *Lasiodiplodea theobromae* (Pat.) Griffon & Maubl both of which cause storage root damage. The inhibitory action of that substance suggest that periderm chemical components act as protecting barrier against soil microorganism (Ki-Cheol, 1990; Peterson, et al., 2003).

Lignification and suberization are closely linked and are dynamic processes that are activated against external damages; they act as a response to external change. Lignin is a chemical compound that gives strength, rigidity and protection to the skin of storage roots of sweetpotato. Lignin has an adhesion force that holds the cells together, thus, giving firmness to tissue (Boudet, 1998).

Many studies provide evidence that lignification is a programmed process. This process occurs with the participation of various tissues, enzyme regulation (oxidation) and participation of leader proteins. This combined participation can provide the amount of lignin in the right places and at the required time (Boundet, 2000).

Skin adhesion / Skinning

The adhesion of the periderm of sweetpotato is important to minimize accidental injury or poor physical handling during harvesting and subsequent handling of sweetpotato roots. Skin adhesion is a genetic characteristic that varies from a cultivar to another, or between the same plants within a cultivar depending on environmental conditions and handling. When cured at 30 °C and a relative humidity of 50 % to 85%, skin adhesion is improved. Changes in relative humidity affect skin adhesion. When humidity is low, skin looses moisture and becomes weaker. In high humidity, the skin

becomes turgid with greater adhesion and becomes more resistant to injury and harder (Blankenship and Boyette, 2002).

Anatomical studies of root periderm establishment at various temperatures showed that ‘Beauregard’ was more susceptible than ‘Jewel’ to skin damage after different periods of storage. Roots of ‘Jewel’ had weak skin at harvest, but skin hardiness increased after several weeks. However, shortly after, skin hardiness was again lost (Villavicencio et al., 2007).

Growth temperature affected skin adhesion and enzymatic activity at high temperature (34/31 º C-8 º C day/night) roots were smaller and had harder skin than roots grown at lower and transitional temperatures (27/24 ºC-8ºC and 20/17 ºC-8ºC). Curing improved skin adhesion, but the effect of curing was related to growing temperature (Gordon, 2008; Clark et al., 2013; Kivuva, et al., 2015). In another study, the periderm of sweetpotato storage roots showed that anatomical and structural composition of the cell wall depends on growing temperature (Villavicencio et al., 2007).

Ethylene / Devining on skinning

There are cultural practices which enhance skinning resistance to damage, such as, removing vines (devinning) 5-7 days prior to harvest (Smith and Wright, 1994). Breeding programs have prevented the spread of improved cultivars with hard skin due to the rejection of this feature by consumers. However, cultivars with a tougher skin to avoid injuries at harvest and improve mechanical harvesting need to be evaluated for their acceptance. Another practice used, but not authorized, is the application of ethephon to reduce losses due to skinning (Cooksey et al., 1993; Main et al., 2009; Wang et al,. 2013).

Ethylene and other enzymes increased the respiration rate, peroxidase and other enzymes; these compounds were investigated in fresh sweetpotato storage roots during curing and after curing. Ethylene and other compound increase the respiration rate. When ethylene was removed, the respiration rate declined rapidly and peroxidase activity too, this has direct effect in lignin activity. Therefore, ethylene may activate the lignification process influencing skinning resistance through enzyme activation (Amand and Randle, 1991).

Wound healing

Short shelf life is a major constraint in the conservation of sweetpotato root for marketing. Therefore, there are been several studies concerning shelf life particularly as a food security crop for developing countries. Humidity conditions are important and directly affect the durability of storage roots of sweetpotato. The deterioration is initiated by the loss of water through the unhealed wounds or poorly healed wounds by the lack of proper moisture. Therefore, research has been conducted to determine the optimal level of humidity for proper curing of skin wounds of sweetpotato. It is known that cultivars with low dry matter content have a lower level of healing compared to cultivars with high dry matter content . (LaBonte and Wrigth, 1993; Rees and Oirshot, 2000; Lulai and Suttle, 2004; Arif, 2013).

The wounds in the periderm consist of cell layers arranged in a similar way to the native periderm or skin without damage. After lignification, they may confer the same protective barrier as the original cell. The thickness of the wounded periderm may vary according to cultivar. Thickness will vary from four to ten layers (Rees et al., 2008).

Walter and Schadel (1983) conducted that an injury requires at least 4 layers of lignified cells to be effective against water loss and to prevent the entry of pathogens. The lignification process begins with the deposition of lignin in the inner walls of the cells exposed to the outside, and then this process is passed into the interior layers of cells until complete sealing of the wound is achieved. Analysis of tissues in the areas of the wounds healed indicated 14% more lignin than normal tissues.

Wounded sweet potato roots increase their respiratory activity. Ethylene was produced at rate of 100 µl per liter, which activated the respiratory process. A high activity of mitochondrial membrane protein was found on sliced sweetpotato root wounded tissue (Makimoto and Asahi, 1981).

Injured potatoes have a distinct ethylene production pattern depending on storage conditions and type of wound. A test was performed with cured freshly harvested sweetpotato roots and wounded sweetpotato roots at a temperature of 15 ° C for a period of 22 weeks. The wounded roots produced 30% more ethylene than healthy harvested roots. The maximum ethylene production was obtained 2 to 4 days after wounding. Ethylene was detected 6 hours after wounding (Randle and Woodson, 1986).

Rapid healing is crucial for the protection of sweetpotato roots after harvest to prevent water loss and entry of pathogens. Tests were conducted on suberization or lignification induced by abscisic acid externally applied (Lulai and Suttle, 2004). The external application of ABA was conducive to the protection of exposed cells avoiding dehydration and loss of water vapor at the site of the cells exposed to the wound. Such application has been called induced suberization (Lulai et al., 2008).

Harvest and Curing

The best time to being harvesting sweetpotato roots is when soil is dry and the air temperature is high. Temperatures below 12 °C will cause significant losses. Sweetpotato roots must be harvested immediately when weather conditions are appropriated. In addition, curing should be performed correctly and with the proper time. Curing depends on the cultivar. Therefore, curing time will vary. Cultivars that heal fast have greater opportunities to prevent infection by pathogens compared to cultivars that heal more slowly. The same situation occurs in to the prevention of water loss and impaired quality of sweetpotato roots (Walter et al., 1983; Grace et al., 2014).

Curing of the roots of sweetpotato is done in order to heal injuries in the roots and keep them in good condition for marketing during the winter and to conserve propagation material for the next planting season. Curing the wounds occurs to a temperature of 29 ° C with a relative humidity of 85 to 90%. Curing is performed immediately after harvest. Curing is the formation of cells similar to the original that were lost in the skin. Features and functions are similar to those of the skin; the only difference is that these are called corky due to high suberization and lignification. Curing depends on the characteristic of each cultivar. Sweetpotato roots exposed to 29 ºC and 30 ° C, initiated a cork layer formation in the wounded area in a period of 2 days, and in 5 or 6 days had a well-developed cork layer. At temperatures below 12 °C, the formation of cork does not occur. The ideal curing conditions are 29 °C and 90% relative humidity for about 5-7 days. The problem for producers is that not every producer has houses for curing (Summer, 1984; Blankenship and Boyette, 2002; Liberty, 2013; Chimney, 2013).

Mechanical properties of the plant cell wall.

The cell wall of higher plants is a tough, flexible and sometimes rigid layer. It provides structural support and protection. The cell wall acts as a filtering mechanism. The major function of the cell wall is to act as a pressure vessel, preventing overexpansion when water enters into the cell. The cell wall is formed by material consisting of microfibers embedded in a complex matrix of polysaccharides, hemicelluloses, and cellulose. The structure of the cell walls of plants is a complex organized; their role is made the structure of plants, the squeleton that support all physical stress. In addition, cell wall has a chemical and physiological function (Klintworth and Stronge, 1988; Gorzelany, 2000; Fan, 2008; Sadowska et al., 2004).

The mechanical qualities of the cell walls allow it to form a microstructure bearing against various external and internal forces that impact the cell wall. Vertical stress in 90-degree angle to the surface (tensile stress) causes cell wall elasticity, thus, bending. Moreover, horizontal stress (shear stress) causing detachment of cell joints in their neighboring cells. Resistance that occurs in the cell wall of these external forces depends on the relative density of the cell components; the relative density is given by the thickness of the cell wall divided by the height of the cell wall over the density of the cell cytoplasm (Klintworth, 1988; Silva, 1995; Chanliaud et al., 2002). The following formula (Silva et al., 1995; Gibson and Ashby, 1997; Gibson, 2012) defines the elastic deformation mechanisms of soft woods in tension, the calculation of the relative density of the cell wall:

$$\textbf{Relative density} = \frac{\rho^*}{\rho_s} = \frac{2}{\sqrt{3}} * \left(\frac{l}{t}\right) \quad (2.1)$$

(P^*) is the density of cellular solids. (Ps) Represent the solids made. (l) is the length of the cell wall. (t) is the thickness of the cell wall.

CHAPTER III

MATERIALS AND METHODS

Experiment 1. Determine the morphological differences and the breaking point of the periderm of sweetpotato storage roots with four mechanical testers.

Objectives:

1. Determine the suitability of four instruments (Skinometer, Force gauge, Torquometer, and Instron) to measure the resistance of the periderm in sweetpotato storage roots.
2. Compare the resistance of the periderm with skin thickness differences among cultivars.

Suitability of four instruments to measure shear and tensile resistance to fracture.

In 2011, four instruments were used to determine shear and tensile resistance to fracture of sweetpotato storage roots. The instruments were evaluated for accuracy, and precision, reliability, and suitability immediately after mature storage roots were harvests at the Pontotoc Ridge-Flatwoods Branch Experiment Station. Plant spacing was 101.6 X 30.48 cm and followed standard production practices were followed (Smith and M.E. Wright, 1994). The cultivars used in this study were “Beauregard-14”, “Beauregard-63”, “Evangeline”, “Covington”, “L07-146”, “L07-6R”, “Hatteras”, and “Jewel”. The instruments used for this test were the Force gauge. IMADA. Model: DS2-11 3100. (Dundee Rd., Suite 707, Northbrook, IL 60062 USA). The force gauge had the capacity to measurement from zero to 50 Newton. The Torquometer, the Halderson tester attached to a Torquometer, Model TQS050FUA. TORQOMETER® Snap-on Incorporated, P.O.

Box 1410, Kenosha, WI 53141-1410. At the edge end of the tester was adhered a disc of sand paper No. 5 (3M™ Paper Sheet 435N, 02356, 10.5 cm x 27.5 cm 100 C-weight, St. Paul, MN 55144-1000) with a diameter of 8 mm. The disc covered an area of 12.5 mm^2 at the point where the test was taken. The sand paper disc was adhered with double side glue tape 3-3M™ (St. Paul, MN 55144-1000), to perform the shear test. This device indicated the maximum torque reading reached in the shearing and tensile test to the skin during the measured skin set value in Newton per Meters. The test was performed vertically on the roots until the pressure exerted on the instrument achieved full detachment of the skin in the affected area of 12 mm-2. The Skinometer, is described as follows; device made by North Carolina State University, which directs a jet of water under the range of pressures from 483KPa to 827 KPa for 20 seconds, with the 0.10 mm diameter of nozzle at the tip end. The water jet acts vertically on the skin surface of the root, releasing the outer cell layers to the inner layers of the center of the area of action towards the periphery of the impact site of the water jet breaking through the phellem to shear it from the phelloderm. The skin fractures were recorded after each sample was tested.

At the Food Sciences Laboratory located in the Herzer Building. Mississippi State University. Mississippi State, MS, 39762. The tensile and shear test with the Instron was performed, (Model 1011). A compress mechanism was used to evaluate the mechanical properties of material and components using tension, compression, flexure, fatigue, impact, torsion and hardness tests. The Instrom consists of a crosshead with travels speed of 50 mm/min. Calibrated at 50 kg of pressure, 10 millimeter depth into the periderm, the puncture device will be 10 mm in diameter. This test was made in the equatorial area of

the root. The mechanical characteristics were expressed by compression Kg·cm-2, (Instron, 2014). The experimental design was a randomized complete block design. Analysis of Variance (ANOVA) analyzed data, and means were separated using LSD ($P < 0.05$) using SAS 9.2 program SAS Institute Inc.100 SAS Campus Drive Cary, NC 27513-2414 USA.

Shear and tensile force determination.

In 2012, at the Pontotoc Ridge-Flatwoods Branch Experiment Station, North Mississippi Research and Extension Center, Mississippi State University, 8320 Highway 15 South, Pontotoc, MS 38863, the following experiment was conducted: Shear and tensile force determination. The cultivar "Beauregard-14" was chosen for this experiment because it is the most used by the farmers in Mississippi. Plant spacing was 101.6 X 30.48 cm, and standard production practices were followed (Bonsi al., 1992; Smith, and Wright, 1994). Two instruments were used to determine the shear and tensile force to fracture the skin of mature sweetpotato storage roots immediately after harvest. The force gauge and the torquometer were as previously described. The first instrument used was the force gauge. The resistance to peeling, which had three measurements, was determined; first, the tensile plus the shear force together were analyzed. They were determined with a tip 10 mm wide, and 10 cm length by measuring the force required to fracture the skin. The fracture made was tangential to the skin surface by the tensile and shear pressure made by the force gauge. The second measurement, the shear test was made alone, and made a parallel cut over the skin of the storage sweetpotato roots, 10 mm wide, and 3 cm length. This cut was necessary to avoid the tensile force, and then proceed to get the shear force ten times for each 25-root sample. The last one was the

determination of the tensile force alone. It was necessary to adapt an extension at the tip end of the force gauge with a serrated thumb forceps 11.43 cm long, and 10 mm length, tied with plastic tape to the tip's edge of the force gauge. Serrated forceps were used on the tissues; teeth will damage tissue less than a smooth surface, and it can grasp with less overall pressure the skin samples. The force recorded in Newton of pressure needs to be realized. Moreover, to determine the tensile force, it was necessary to peel the skin; three fine and delicate sashes of skin were taking for each 25-root sample of the cultivar "Beauregard-14". They were then placed into the container filed with water, to avoid dehydration of the samples, in time the tensile force was taking. The data recorded was used for future statistical analysis.

The second instrument used was the Torquometer, with a diameter of 8 mm. The disc covers an area of 12.5 mm^2 at the point where the test site was taken. The sand paper disc was adhered with double side glue tape 3-3M™ (St. Paul, MN 55144-1000), to perform the shear test. This device indicated the maximum torque reading reached in the shearing and tensile test to the skin during the measured skin set value in Newton per meters. The test was performed vertically on the roots until the pressure exerted on the instrument achieved by full detachment of the skin in the affected area of 122.7 mm^2. The data recorded was used for future statistical analysis. To determine the shear test alone, it was necessary to perform a cut with a cork hole-borer with a diameter of 12.5 mm, and then take the shear test from this area of the skin.

Experiment II. Anatomical characterization and lignin content in sweetpotato storage roots.

Objective:

Determine periderm anatomical characteristics and chemical characteristic of sweetpotato storage roots in seven cultivars and associate periderm anatomical and chemical characteristics with skinning resistance.

The periderm is a multilayered tissue system very complex in functions and constitutions. It had three tissues from the outside to the inside: the phellem, the phellogen, and the phelloderm. Their number of cell layers varies among different species; the most important function of the periderm is to reduce the loss of water and solutes from the interior tissues and to protect the plant from soil borne diseases and unfavorable environmental conditions (Sumner, 1984; Walter, 1989; Kum, 1991; Quierien et al., 2006; Villavicencio et al., 2007). For these conditions, the number of cell layer and lignin content with the confocal microscopy in the fluorescence mode were determined. In addition, the NIR System was used to determine lignin content as a complementary research. The storage roots from the following cultivars used for this study were “Beauregard-14”, “Beauregard-63”, “Centennial”, “Covington”, “L07-146”, “L07-6R”, “Hatteras”, and “Jewel”, provided from the Pontotoc Ridge-Flatwoods Branch Experiment Station (MS), as previously described.

At the Institute for Imaging & Analytical Technologies. I^2AT East Facility, Mississippi State University. MS. 39762. Carried out the lignin determination. Fluorescent images were acquired from a Zeiss LSM 510 Confocal Laser Scanning Microscope (Carl Zeiss Microimaging, Inc.) with an Inverted Zeiss Axiovert 200 M Light microscope and a plan apochromatic 20 X/0.8 NA objective lens. A DAPI/FITC (DAPI/Fluorescein) filters set used in Single channel mode imaging. Excitation

wavelengths of 405 nm/488 nm and Band Pass (BP) Emission wavelengths of 420-480 nm (Blue) and Long Pass (LP) 505 nm (Green) were acquired at a 1024 x 1024-pixel format for imaging purposes (Monroe, 2012).

In a Laser Scanning Microscopes (LSMs), a fluorescent light detected in time the laser bean scanned across a sample. “The light emitted from the scanned area corresponds to a number of tiny, contiguous regions called pixels, collected over short time intervals. All signal captured converted to a digital pixel value and the collection of all the pixels from the scanned region defines the image” (Pologruto et al., 2003). The fluorescence obtained from the phenolic ring that is part of the chain of the lignin/suberin compounds in the cell walls of the periderm (Nelson and Cox , 2008) These compounds accumulated into the cell walls make easy to differentiate the tissues and count the cell layers for each one. After the microphotographs were taken; they were observed, and detailed counting for each tissue. It was done in sequential manner. To determine the lignin content at the Band Pass (BP) Emission wavelengths of 420-480 nm (Blue) was determine the intensity of the light in pixels per micrometers (pμm); there was a perpendicular line in order to measure the image sample, which had a 200 μm in length. This obtained the intensity of bit depth for the fluorescent light recorded in the picture. The greater the bits, the greater the number of “intensity” that can be represented. For a 12-bit data set, the intensities will be represented from zero to 4096 values. The experimental design was a randomized complete block design. Data analyzed by Analysis of Variance (ANOVA), and means were separated using LSD ($P < 0.05$) using SAS 9.2 program SAS Institute Inc.100 SAS Campus Drive Cary, NC 27513-2414 USA.

At the Forage Quality Laboratory at Dorman Hall, Mississippi State University, 320 Dorman Hall, MS 39762, using the FOSS NIR System, the lignin content of the skin of sweetpotato storage roots was determined. This system had the most significant advantage for laboratory analysis with the elimination of sample handling, manipulation, and requiring less time for analysis. The sample unit was from three roots from each cultivar. The samples dried at the oven at 50 ºC for 72 hours. Then, the samples were grounded. The Ring cup was used (Legume Hay) for exposure of the samples to the infrared light. For each sample, three reading with the NIR system to have enough data for comparison proposes was made. The relative density was calculated with the formula previously defined for the relative density for elastic deformation mechanisms of soft woods in radial tension (Mode´n1 and Berglund, 2008). The data obtained was recorded in excel format for future analysis with Statistical analysis with SAS 9.2 and means were separated using LSD at P <0.05, <0.001.

Experiment III. Evaluating preharvest cultural practices to enhance the sweetpotato storage roots skin set.

Objective.

Determine the effect of preharvest strategies on skinning resistance in sweetpotato storage roots.

Preharvest cultural practices were evaluated at the Pontotoc Ridge-Flatwoods Experiment Station (Pontotoc, MS) in 2012. Practices included were Ethephon rates and application time, and defoliation /devinning at different time. The cultivar "Beauregard-14" sweetpotato was chosen for this experiment because it is the main cultivar cultivated in Mississippi. Plant spacing was 101.6 X 30.48 cm and standard production practices were followed (Bonsi et al., 1992; Smith and Wright, 1994). Treatments consisted in

preharvest foliar application of ethephon (Prep: Bayer CropScience, Research Triangle Park, NC) 1.68 and 0.84 kg / ha a.i. Treatment time for defoliation/ devining and ethephon application were at 1,3, and 7 days before harvest (DBH). Defoliation was done with a two-row flail mower deviner (model FB-080; United Farm Tools, South Charleston, WV). For this experiment, Control treatment was defoliated at harvest. The sample unit was three roots from three plants. Lignin content was determined with the fluorescent mode at the Institute for Imaging & Analytical Technologies, as previously described.

Three samples from each root were analyzed, and fluorescent images acquired after lignin content was determined as previously described. The microphotographs were used for the measurement of the cell wall thickness, cell length, and periderm length. At the Forage Quality Laboratory, previously described. Lignin content with the FOSS NIR System was determined. The experimental design was a randomized complete block design. Analysis of Variance (ANOVA) analyzed data and means were separated using LSD ($P < 0.05$) using SAS 9.2 program SAS Institute Inc.100 SAS Campus Drive Cary, NC 27513-2414 USA.

Experiment IV. Evaluate changes in skin characteristics due to curing and without curing of sweetpotato storage roots

Objective

Determine anatomical and chemical skin characteristics due to curing.

This experiment was conducted at the Pontotoc Ridge-Flatwoods Branch Experiment Station, North Mississippi Research and Extension Center, Mississippi State

University, 8320 Highway 15 South, Pontotoc, MS 38863. Cultivars used for this study were “Beauregard-14”, “Beauregard-63”, “Centennial”, “Covington”, “Evangeline”, “L-07-146”, “L07-6R”, “Hatteras”, and “Jewel”. Plant spacing was 101.6 X 30.48 cm and followed standard production practices were followed (Thompson et al., 2002). The experimental plot consisted of four 6 m rows. Three plants from the middle two rows were selected and all storage roots were harvested. Approximately 10 to 12 kg of storage roots from each cultivar were selected to be cured immediately at 29.6 ^{o}C and 80% to 85% Relative Humidity (RH) in a walk-in growth chamber for 7 days. After curing, samples were taken to compare curing with non-cured storage roots from each cultivar for determination of the tensile and shear force with the force gauge IMADA, and the Torquometer as previously described. Determination of lignin with the confocal microscope in the fluorescent mode as previously described. The relative density was calculated with the formula defined before for the relative density for elastic deformation mechanisms of soft woods in radial tension (Mode´n1 and Berglund, 2008). Analysis of Variance (ANOVA) analyzed data and means were separated using LSD ($P < 0.05$) using SAS 9.2 program SAS Institute Inc., 100 SAS Campus Drive Cary, NC 27513-2414 USA.

Experiment V. Evaluated anatomical changes during the wound healing process with and without curing.

Objective

Determine anatomically and chemically changes in the skin due to the healing process.

This study was conducted at the Pontotoc Ridge-Flatwoods Branch Experiment Station, North Mississippi Research and Extension Center, Mississippi State University,

8320 Highway 15 South, Pontotoc, MS 38863. The cultivars used for this study were "Beauregard-14", "L-07-146", and "L07-6R". Plant spacing and standard productions procedures, and selection of the plant to harvest was as previously described (Bonsi, 1992). Storage roots from each cultivar were selected to cure immediately at 29.6 ^{o}C and 80% to 85% Relative Humidity (RH) in a walk-in growth chamber for 3 and 7 days. In addition, storage roots, were artificial wounded to analyze the healing process during curing, samples were selected, and taken to compare curing with non-cured storage roots from each cultivar. Lignin determination was conducted at the Institute for Imaging & Analytical Technologies. I^2AT East Facility, Mississippi State University. MS. 39762. A Zeiss LSM 510 Confocal Laser Scanning Microscope was used to acquire fluorescent images. The relative density was calculated with the formula previously defined for the relative density for elastic deformation mechanisms of soft woods in radial tension (Mode´n1 and Berglund, 2008). Analysis of Variance (ANOVA) analyzed data and means were separated using LSD ($P < 0.05$) using SAS 9.2 program SAS Institute Inc., 100 SAS Campus Drive Cary, NC 27513-2414 USA.

CHAPTER IV

RESULTS AND DISCUSSION

Experiment 1. Determine the morphological differences and the breaking point of the periderm of sweetpotato storage roots with four mechanical testers.

As shown in Figure 4.1, the confocal microscope with a lens resolution of 20X, clearly determined the differences between tissues that compose the sweetpotato skin; the outside layer the phellem that clearly defined fluorescent cell walls, followed by the phellogen, and the phelloderm.

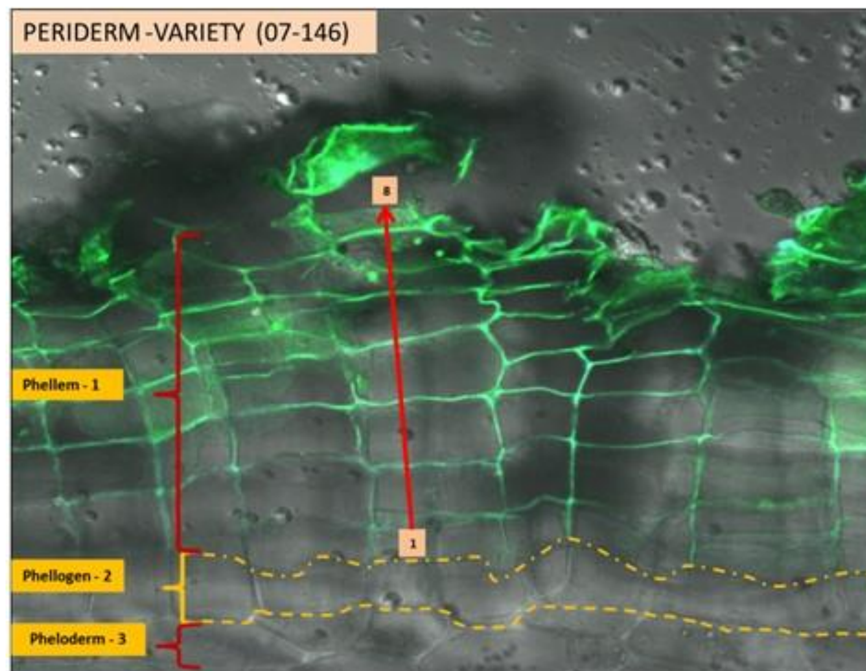

Figure 4.1 Microphotograph showing the distribution of the tissues, which compose the periderm called skin of the storage root of sweetpotato.

Observed with the confocal microscope 20X. 1. Phellem. 2. Phellogen. 3. Phelloderm.

When using the torquometer, results showed that shear force plus tensile force was greatest compared with the shear force and tensile force alone. However, tensile force was lowest (Table 4.1).

When using the force gauge, results showed that shear force plus tensile force was greatest compared to the shear force and tensile force alone. However, tensile force was the lowest (Table 4.2).

Table 4.1 Shear and Tensile force of sweetpotato periderm, cultivar "Beauregard-14" as measured with the Torquometer.

Instrument	**Shear +Tensile force (N·m)**	**Shear force (N·m)**	**Tensile force (N·m)**
Torquometer	0.29 a^{z}	0.24 b	0.04 c

^{z}Means across columns with the same letter are not significantly different by Turkey's test at $P \leq 0.05$ (n=25).

Table 4.2 Shear and Tensile force of sweetpotato periderm, cultivar "Beauregard-14" as measured with the Force gauge.

Instrument	**Shear +Tensile force**	**Shear force**	**Tensile force**
	(N)	(N)	(N)
Force gauge	1.51 a^{z}	1.08 b	0.4 c

^{Z} Means across columns with the same letter are not significantly different by Turkey's test at P ≤ 0.05 (n = 25).

Figure 4.2 Shows the sequential order for determining the shear plus tensile force with the torquometer. Note the differences between taking the tensile and shear force together into the skin; it made a peripheral ruptured off the skin (figure 4.2-B), and when the shear stress it is determined, it made a concentric rotation because the tensile force was eliminated (figure 4.2-D).

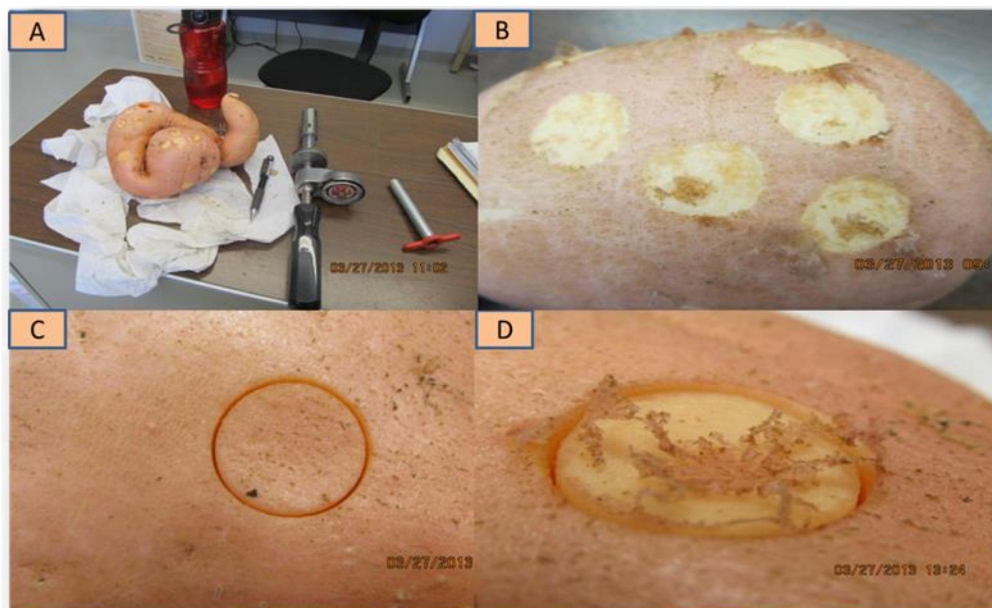

Figure 4.2 Tensile and shear stress determined of the periderm of sweetpotato storage roots with the Torquometer.

(A) Torquometer, and cork hole. (B) The wound of the periderm made with the torquometer after the Tensile and Shear force were determined. (C) The sample area made with the cork hole to eliminate the tensile force effect. (D) Sampled area after determination of shear force with the torquometer.

Shear and tensile force (a measure of skin toughness or force required to break the skin) of eight cultivars was measured with the force gauge, force expressed as Newtons (N). Results showed that “Covington” required the greatest force to break the skin

followed by “Evangeline”, “Beauregard -63”, with the “Jewel” required the least force (Table 4.3).

Table 4.3 Shear and the tensile force of the skin of sweetpotato storage roots as determined by the force gauge at harvest.

Cultivar	**Shear and Tensile forces (N)**
“Covington”	1.66 a[z]
“Evangeline”	1.36 b
“Beauregard-63”	1.22 c
“Beauregard-14”	1.14 d
“Hatteras”	1.03 de
“L07-146”	1.00 ef
“Jewel”	0.90 f

[z] Means with the same letter are not significantly different according to the LSD at $P \leq 0.05$ (n=30).

Figure 4.3 illustrates the tensile and shear force as determined by a force gauge. It shows the sequential order for determining the shear force and tensile force alone (figure 4.3-A-D). Note the differences between taking the tensile and shear force together into the skin, (figure 4.3-C), and the tensile force alone (figure 4.3-B and figure 4.3-D).

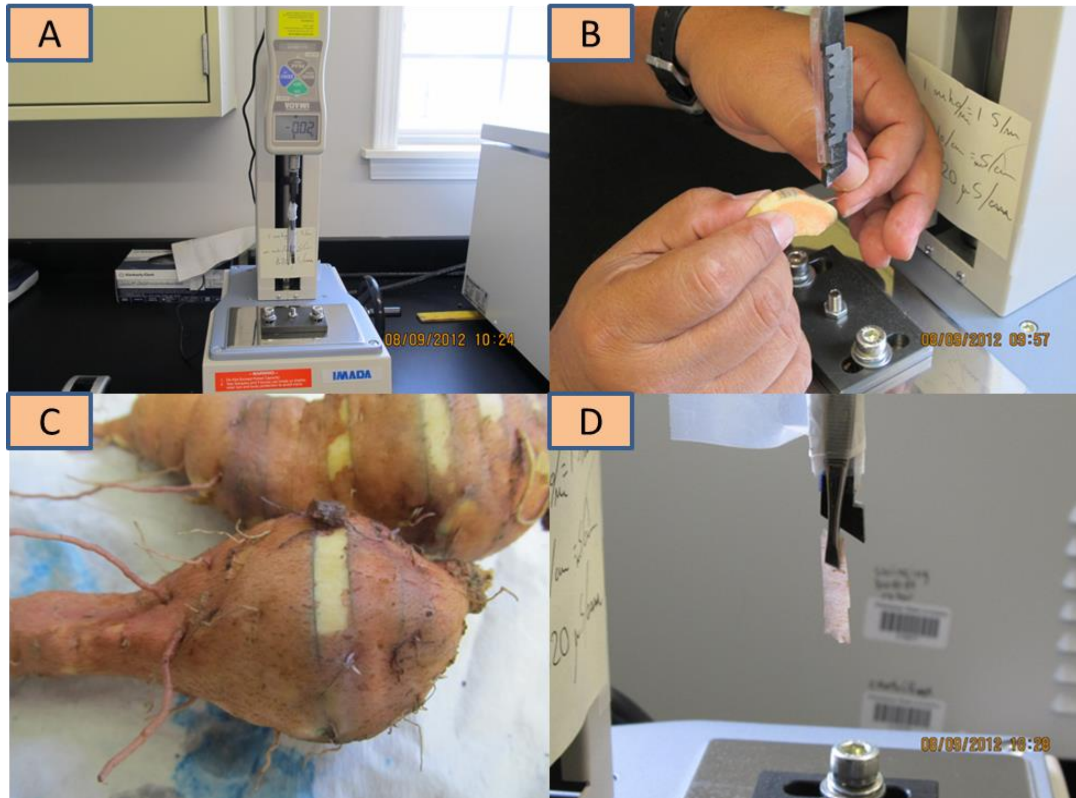

Figure 4.3 Tensile and shear forces of the periderm of sweetpotato storage roots determined with the force gauge.

(A) Force gauge. (B) Scraping the skin against the force gauge. (C) Wound after shear and tensile force determination of the skin. (D) Determination of the tensile force of the skin by pulling the skin until fractured.

Skin toughness (pressure expressed as kPa) of eight cultivars at harvest was measured with the Skinometer. Skin of “Beauregard-63” and “Beauregard-14” was the toughest, requiring a greater force to breaking the skin, 761.9 kPa, and 741.2 kPa,

respectively, followed by “Jewel” with 698.5 kPa. There was no difference in skin toughness among the remaining cultivars (Table 3.4).

Table 4.4 Pressure at which water of the skinometer induced within 20 seconds skin fracture of the storage sweetpotato root at harvest.

Cultivar	**Pressure (kPa)**
“Beauregard-63”	761.9 a[z]
“Beauregard-14”	741.2 a
“Jewel”	698.5 b
“Evangeline”	589.5 c
“Hatteras”	582.6 c
“Covington”	565.4 c
“L07-146”	548.1 c

[z] Means with the same letter are not significantly different according to the LSD at $P \leq 0.05$ (n=10).

Resistance to shear plus tensile force to fracture the skin in sweetpotato storage root as determined by the Torquometer, torque expressed as Newton per meter (N•m) is shown in Table 4.5. "Covington" required the greatest torque of 0.210 N•m to reach the breaking point. Cultivars with the lowest torque were "L07-146" and "Jewel" with 0.166 N•m, and 0.165 N•m, respectively.

Table 4.5 Shear and the tensile force required to break the skin of sweetpotato storage roots of seven cultivars at harvest as determined by the torquometer.

Cultivar	**Torque (N·m)**
"Covington"	0.210 a[z]
"Evangeline"	0.202 a b
"Beauregard-63"	0.195 a b c
"Beauregard-14"	0.174 c b
"Hatteras"	0.172 c b
"L07-146"	0.166 c
"Jewel"	0.165 c

[z] Means with the same letter are not significantly different according to the LSD at $P \leq 0.05$ ($n = 9$).

Shear plus tensile force required to fracture the skin of sweetpotato storage roots of seven cultivars as determined by the Instron (pressure expressed as kg·cm-2) is shown in Table 4.6 "Evangeline" required the greatest pressure 24.78 kg·cm-2 to reach the breaking point of the uniaxial penetration. The lowest ranking cultivars were "Jewel", with a pressure of 21.85 kg·cm-2, and "Hatteras", with a pressure of 21.57 Kg·cm-2. Cultivars with intermediated response in resistance to shear and tensile force included "L07-146", "Beauregard-14", and "Beauregard-63", with pressures of 23.67 Kg·cm-2, 22.82 Kg·cm-2, and 22.48 Kg·cm-2, respectively.

Table 4.6 Shear and the tensile force required to break the skin of sweetpotato storage roots of seven cultivars at harvest as determined by the Instrom.

Cultivar	**Pressure (Kg/cm^2)**
"Evangeline"	24.78 a[z]
"Covington"	24.71 a
"L07-146"	23.67 a b
"Beauregard-14"	22.82 c b
"Beauregard-63"	22.48 c b
"Jewel"	21.85 c
"Hatteras"	21.57 c

[z]Means with the same letter are not significantly different according to the LSD at $P \leq 0.05$ (n = 14).

Figure 4.4 shows the tensile and shear force applied to the skin of sweetpotato storage roots with four devices to measure the forces; the force gauge (Figure 4.4-A), the skinometer (Figure 4.4-B), the Instron (Figure 4.4-C), the torquometer (Figure 4.4-D).

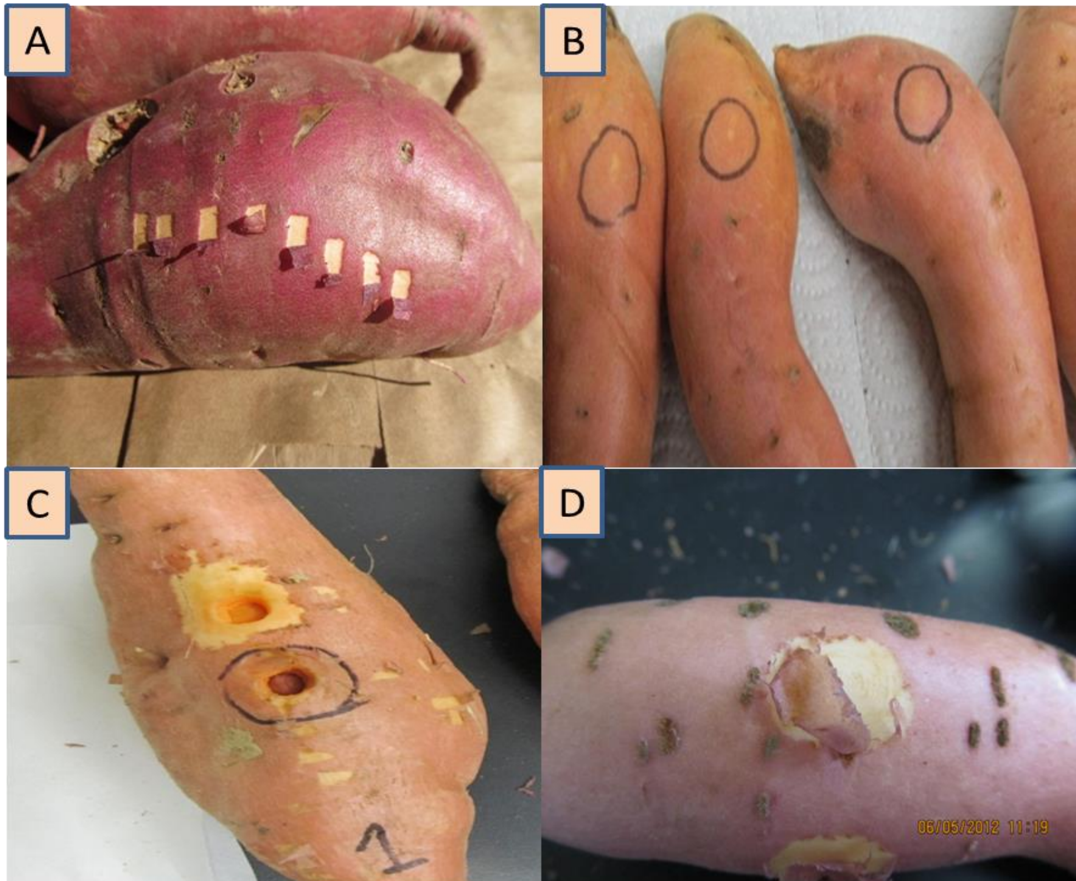

Figure 4.4 Photographs of sweetpotato storage roots showing scars made after measuring the shear and tensile stress of the skin by four instruments.

(A) Force gauge, (B) Skinometer, (C) Instrom, and Moreover (D) Torquometer

The resistance to shear plus tensile force to fracture the skin in sweetpotato storage root as determined by the torquometer and the force gauge is shown in Table 4.7. When considering the force needed to reach the breaking point of the skin, "Jewel" had the greatest coefficient of variation (24%) with the torquometer, and a coefficient of

variation (25%) with the force gauge. The lowest coefficient of variation was shown by "Covington" with a torque of 3%, and a force of 2 %.

Table 4.7 Statistical descriptive parameters comparing the Force gauge and the Torquometer used to measure the force of storage roots of seven cultivars at harvest.

Cultivars	Torquo-meter Torque (N·m)	Force-gauge Force (N)	SD[z] Torque	SD Force	SE[y] Torque	SE Force	CV[x] Torquo-meter (%)	CV Force-gauge (%)
"Beauregard-14"	0.196 ab[w]	1.747 ab	0.022	0.122	0.013	0.070	11	7
"Beauregard-63"	0.211 a	1.741 ab	0.026	0.094	0.015	0.054	12	5
"Centennial"	0.166 c	1.600 c	0.026	0.186	0.015	0.107	16	12
"Covington"	0.174 b	1.652 c	0.006	0.031	0.003	0.018	3	2
"Evangeline"	0.203 a	1.706 b	0.016	0.100	0.009	0.057	8	6
"Hatteras"	0.166 c	1.708 b	0.003	0.066	0.002	0.038	2	4
"Jewel"	0.173 b	1.771 a	0.041	0.444	0.024	0.257	24	25

[z] SD = Standard Deviation.
[y] SE = Standard Error.
[x] CV = Coefficient variation.
[w] Means in the columns with the same letter are not significantly different according to the LSD at $P \leq 0.05$ (n = 9).

One of the main problems with sweetpotatoes at harvest is the excoriation or skinning due to mechanical harvest and handling to the storage facilities (O'Brien and Scheuerman, 1968). There are many studies concerning the design of some mechanical harvesters to avoid the damage the storage roots. Twenty percent of the marketable sweetpotato storage roots are left in the ground (Summer,1984). There are studies that characterized the mechanisms and biochemical process involved in sweetpotato skin adhesion. Skinning occurs when the phellem is separated from the phellogen cells by the friction, rubbing, rebound at harvest (Lulai and Freeman, 2001; Plavlista, 2002; Villavicencio et al., 2003).

Of the three tissues in the periderm of the sweet potato, the phellem at the outer layer is accountable for the tensile force (± 20%), while the phellogen is accountable for the shear force (± 80%) in the potato tubers at the time of harvest. The torquometer and the force gauge used this experiment to determine the differences between these forces at harvest found significant differences with and without the phellem. This confirms the distribution of the forces among the tissues, which constituent the periderm, and their relation to skin adhesion. A similar study done with potato tubers found the distribution of the shear force in the phellogen, and the tensile force in the phellem (Lulai, 2002).

The torquometer has been used in different studies to determine the resistance of the periderm of tubers and roots at harvest. One particular study determined the feasibility of measuring genotypic differences in skin set at harvest and demonstrated that the torquometer was sufficiently sensitive to measure genotypic and phenotypic differences in skin set in potato tubers (Lulai and Orr, 1993). Another experiment was conducted to determine the effectiveness of the torquometer to detect differences among

treatments in sweetpotato storage roots at harvest (Jett, 1999). In another study researchers found that the differences between cultivars and treatments ranged from 0.150 N•m to 0.450 N•m at harvest (Lulai and Freeman, 2001). Another test performed with four cultivars of potato tubers determined the sensitivity of the torquometer to detect genotypic differences in skin set at harvest. The range obtained was from 0.316 N•m to 0.395 N•m (Lulai, 2002). In this experiment, shear stress plus tensile stress in seven cultivars was determined; the torquometer was sensitive enough to determine the differences between the cultivars in a range from 0.165 N•m to 0.210 N•m. On the other hand, the force gauge was reported to have the capability to determine cultivar differences in the firmness of sweetpotato storage roots. (Wall, 2005). In this experiment, it was possible to use the force gauge to determined shear and tensile forces independently and detect differences between the cultivars.

The Instron device was suitable for determining differences among the cultivars in the pressure needed to penetrate the internal tissues of the storage roots. Similar results were found with the penetrometer (Rees et al., 2002).

Skin adhesion or hardness in sweetpotato storage roots had a positive correlation with temperature, weather condition, soil moisture conditions, and cultivars. Previous findings reported that skin adhesion was influenced by the same factors from one year to another (Villavicencio et al., 2007).

Experiment II. Anatomical characterization and lignin content in sweetpotato storage roots

Table 4.8 shows the number of cell layers in the phellem, phellogen, phelloderm, and a total number of cell layers in the periderm. The cultivar “L07-6R” had the greatest

average of 8.33 cell layers in the phellem. The cultivars “Covington”, “Centennial”, “Hatteras”, and “Jewel” had the very low number of cell layers with 3.83, and 3.17, respectively. The cultivars “L07-6R”, “L07-146”, and “Beauregard-14” had the greatest number of cell layers in the phellogen, and ranged from 1.83 to 2.0 cell layers. The cultivars “Covington” and “Centennial” have the lowest cell layer number in the phellogen (1.0-cell layers) for both. The number of cell layers of the phelloderm did not differ among the cultivars. The periderm cell layers were obtained by adding the cell layer number from the three tissues, which gave the periderm cell layer numbers. Cultivar “L07-6R” had the greater number of cell layers at the periderm with 12.41 cell layers, followed by “L07-146” with 9.70 cell layers. “Centennial”, “Hatteras”, and “Jewel” have the lowest number of all the cultivars with 6.93, 6.40, and 6.26 cell layers, respectively.

Table 4.8 A number of cell layers in the phellem, phellogen, and phelloderm and total number of cell layers in the periderm of eight sweetpotato cultivars as determined by fluorescence microscopy.

Cultivar	Phellem (Number of Cell layers)	Phellogen (Number of Cell layers)	Phelloderm (Number of Cell layers)	Periderm Total Number of cell layers
"L07-6R"	8.33 a[z]	2.00 a	2.08 a	12.41 a
"L07-146"	5.83 b	1.83 a	2.04 a	9.70 b
"Beauregard-14"	4.33 c	2.00 a	2.10 a	8.43 c
"Beauregard-63"	4.33 c	1.17 bc	2.07 a	7.57 c
"Covington"	3.83 cd	1.00 c	2.05 a	6.88 d
"Centennial"	3.17 d	1.00 c	2.09 a	6.26 d
"Hatteras"	3.17 d	1.17 bc	2.06 a	6.40 d
"Jewel"	3.17 d	1.67 ab	2.09 a	6.93 d

[z] Means in columns with the same letter are not significantly different according to Tukey's test at $P \leq 0.05$ ($n = 9$).

The figure 4.5 illustrates the number of lignified cell layers observed with the fluorescent microscope. Cultivar differences are shown in table 4.9.

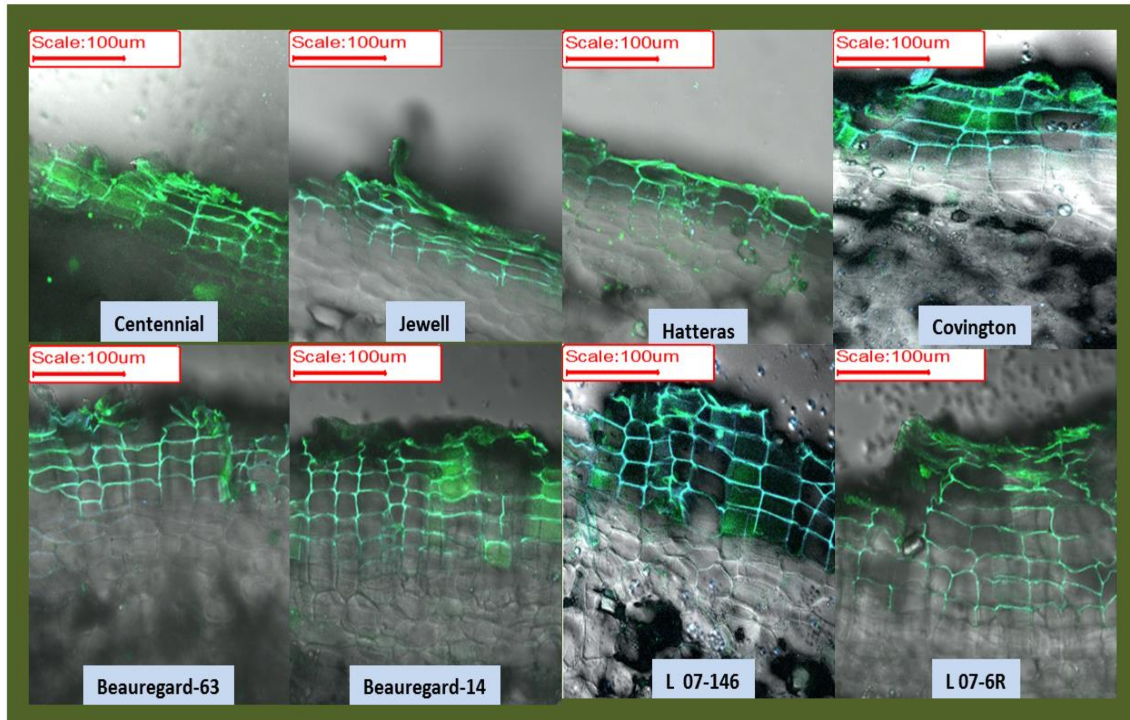

Figure 4.5 Microphotographs showing periderm characteristics of the storage roots of eight cultivars as determined by fluorescence microscopy at harvest.

Periderm thickness for cultivars "L07-6R", "L07-146", "Beauregard-14", "Beauregard-63", and "Covington", ranged from 225.88 µm for "L07-6R" to 189.29 µm for "Covington". Periderm thickness of these cultivars was greater. "Centennial", "Hatteras", and "Jewel" had the thinner periderm with 155.68 µm, 155.60 µm, and 143.63 µm, respectively (Table 4.9).

The number of cell layers in the periderm was greater for cultivars "L07-6R", "L07-146", and "Beauregard-14" with 12.41 cell layers, 9.70 cell layers, and 8.43 cell

layers, respectively. On the other hand, no differences between “Beauregard-63”, and “Covington”, “Hatteras” and “Jewel” were observed among them. The lowest number of a cell layer in the periderm was for cultivar “Centennial” with 6.26 cell layers. The greatest cell height was observed in “L07-6R”, “L07-146”, “Beauregard-14”, which was 35.12 µm, 33.77 µm, and 29.67 µm, respectively. However, there was no difference in cell height among the cultivars.

Cell wall thickness did not differ among cultivars. Relative lignin content for cultivar “Covington” was 2024 pµm, and for “Hatteras” was 2718 pµm and was significantly greater than relative lignin content of the remaining cultivars. The coefficient of correlation was determined for periderm thickness, the number of a cell layer in the periderm, cell height, cell wall thickness, and lignin content. Lignin content was not correlated with periderm thickness, and a number of cell layers in the periderm (Table 4.9).

Table 4.9 Periderm components of sweetpotato storage root of eight cultivars at harvest as determined by fluorescent microscopy

Cultivars	**Periderm thickness (µm)**	**Number of Cell layer in Periderm**	**Cell height (µm)**	**Cell wall thicknes s (µm)**	**Lignin content (pµm)[z]**
"L07-6R"	225.88 a[y]	12.41 a	35.12 a	5.73 a	1016.40 cd
"L07-146"	223.95 a	9.70 a	33.77 a	5.69 a	1758.00 b
"Beauregard-14"	222.78 a	8.43 a	29.64 a	4.98 a	1016.40 d
"Beauregard-63"	218.54 ab	7.57 ab	29.15 ab	4.96 a	1145.90 cd
"Covington"	189.29 abc	6.88 ab	28.93 ab	4.90 a	2024.00 a
"Centennial"	155.68 bc	6.26 b	27.20 b	4.66 a	1319.60 cd
"Hatteras"	155.60 bc	6.40 ab	26.86 b	4.61 a	2718.00 a
"Jewel"	143.63 c	6.93 ab	25.88 b	4.51 a	1602.40 c
Correlation (*r*)		0.73	0.93	0.99	0.17

[z] pµm = pixels per micrometer.
[y] Means in columns with the same letter are not significantly different according to Tukey's test at $P \leq 0.05$ ($n = 9$).

The relationship of periderm anatomy and its chemical composition with skin adhesion and resistance at harvest have been investigated. These characteristics were related to observe differences in reactions from various sweetpotato genotypes to feeding by soil insect and disease resistance at harvest (Schalk et al., 1986). In addition, the thickness of the periderm of 19 sweetpotato entries (cultivars-genotypes), was measured. "Jewel" had a periderm thickness of 122.6µm and phellem thickness of 92.4 µm, and "Centennial" had a periderm thickness of 144.5µm and phellem thickness of 113.6 µm. In addition, they found that for the 16 cultivars, the average of the periderm at 135 days after planting was 189.2 µm, number of the cell layers was 6.7, and cell thickness was 28.3 µm, and the thickness of the phellem was 143.0 µm, number of the cell layers was 4.7 and cell thickness was 30.5 µm. It was found that the thickness of the periderm was associated with increases in the number of cell layers of the phellem tissue. The periderm dimensions for the different cultivars indicated solid environmental extraordinary effects on periderm thickness (Schalk et al, 1986).

Another study on the periderm of the sweetpotato storage roots indicated a different anatomical and structural composition of cell walls, depending on growth temperature. In addition, they concluded that histochemical studies of the periderm of sweetpotato storage roots, cultivar "Beauregard" indicated a similar anatomical and structural composition of the periderm cell walls of roots grown at different sites in Louisiana, Mississippi, and North Carolina. The maximum-minimum periderm thickness (275µm -150 µm) and number of single cell layers (13 – 4 cell layers)were observed at the temperature range of 34/31°C to 20/17°C, respectively (Villavicencio et al., 2007). However, in a previous experiment, it was determined that periderm thickness

diminished and breaking skin resistance increased as soil temperature increased, and water availability decreased, but the number of cell layers remained constant. In addition, skin adhesion or resistance to break was a result of a physiological change in the periderm and adjacent tissues not from structural changes (Webster and Austin, 1972).

Differences among “L07-6R”, “L07-146”, “Beauregard-14”, “Beauregard-63”, “Covington”, “Centennial”, and “Hatteras” were found in this study. Cultivar “L07-6R” had the highest number of cell layers in the periderm 12.41cell layers, and the thickest periderm 225.88 µm. The thinnest periderm was found in cultivar “Jewel” with 6.93 number of cell layers, and periderm thickness of 143.63 µm. Lignin content of cultivars “Hatteras” and “Covington” was the highest with 2718.0 pµm, and 2024.0 pµm, respectively (Table 4.9).

One method to determine the lignified tissues or pectin activity in the skin of sweetpotato storage roots is by special staining methods used in the skin samples, followed by microscopic observation. It was determined that cell layers of the phellem stain differently compared to cell layers in the phellogen, phelloderm and other types of cortical cells (Villavicencio et al., 2007). With the use of fluorescent microscopy in this study, it was found that cell layers of the phellem were brightest when exposed to laser light. The difference in light reflection allowed us to differentiate and identify the various tissue of the skin as showed in figure 4.5.

Results indicate that lignin content followed the same trend when compared to fluorescent microscopy or NIR. “Covington” had the highest lignin content of 177.80 g·kg. Cultivars, “Hatteras”, “L07-146”, and “Beauregard-14” did not differ, having units of 158.53 g·kg-1, 158.43 g·Kg, and 156.13 g·kg, respectively. The cultivars “Beauregard-

63”and “Evangeline” had the lower lignin content of 143.23 g·kg, 142.5 g·kg, respectively. “Evangeline” had the lowest calcium content. The remaining cultivars did not differ in Ca content.

“Evangeline” had the highest ash content of 155.57 g·kg. The lower ash content was observed in “Covington” with 87.8 g·kg-1, and ““L07-6R” with 86.65 g·kg, (Table 4.10).

Table 4.10 Lignin, calcium, ash, and dry matter content in the skin of sweetpotato storage roots of seven cultivars as determined by NIR[z] at harvest

Cultivar	**Lignin content (g·kg)[y]**	**Ca (g·kg)**	**Ash (g·kg)**
“Covington”	177.80 a	33.98 a	87.8 c
“Hatteras”	158.53 b	35.72 a	120.7 abc
“L07-146”	158.43 b	33.20 a	90.26 bc
“Beauregard -14”	156.13 b	35.29 a	100.18 bc
“L07-6R”	147.07 bc	30.55 a	86.65 c
“Beauregard-63”	143.23 c	36.01 a	127.32 ab
“Evangeline”	142.5 c	24.96 b	155.57 a

[z] NIR = Near Infrared System.
[y] Means in the columns with the same letter are not significantly different according to the LSD’s test at $P \leq 0.05$ (n = 9).

The relative skin density of six sweetpotato cultivars was determined as shown in table 4.11. Cell height was greater for “Covington” and “Beauregard-63” compared to the remaining cultivars, but did not differ from cell height of “L07-146” and “Beauregard-14”. “Jewel”, “Hatteras”, “Beauregard-14”, and “L07-146” did not differ in relative skin density. However, “Jewel” and “Hatteras” had greater relative skin density of 0.201 g·cm-3, and 0.198 g·cm-3, respectively. Cultivars “Covington”, “Beauregard-63”, “L07-146”, and “Beauregard-14” did not differ in relative skin density. \

The relative density of the skin was negatively correlated on several parameters; Periderm thickness r = - 0.82 was negatively correlated with all cultivars (Table 4.12).

Table 4.11 Cell heigth, cell wall thicknes, and relative skin densityof sweetpotato storage root of six cultivars at harvest.

Cultivar	**Cell height (µm)**	**Cell wall thickness (µm)**	**Relative Skin Density (g·cm-3)**
"Covington"	35.12 a[z]	5.73 a	0.189 b
"Beauregard-63"	29.64 a	4.98 a	0.194 b
"L07-146"	29.15 ab	4.96 a	0.197 ab
"Beauregard-14"	28.93 ab	4.9 a	0.196 ab
"Hatteras"	26.86 b	4.61 a	0.198 a
"Jewel"	25.88 b	4.51 a	0.201 a

[z] Means within columns with the same letter are not significantly different according to the LSD at $P \leq 0.05$ (n = 9).

Table 4.12 Correlation between the density of cells walls of the periderm with structural and chemical components of sweetpotato storage roots of six cultivars at harvest.

Cultivar	**Relative density of skin**	**Periderm thickness (µm)**	**Number of Cell layers in Periderm**	**Cell height (µm)**	**Cell wall thickness (µm)**	**Lignin content (g·kg-1)[z]**	**Ash (g·kg-1)**	**Ca (g·kg-1)**
"Covington"	0.189 b[y]	225.88 a	8.66 a	35.12 a	5.73 a	177.8 a	87.8 c	33.98 a
"Beauregard-63"	0.194 b	222.78 a	8.66 a	29.64 a	4.98 a	143.23 c	127.32 ab	36.02 a
"L07-146"	0.197 ab	218.54 ab	7.83 ab	29.15 ab	4.96 a	158.43 b	90.26 bc	33.20 a
"Beauregard-14"	0.196 ab	189.29 abc	8.5 ab	28.93 ab	4.9 a	156.13 b	100.18 bc	35.30 a
"Hatteras"	0.198 a	155.6 bc	8.5 ab	26.86 b	4.61 a	158.53 b	120.72 abc	35.72 a
"Jewel"	0.201 a	143.63 c	7.83 ab	25.88 b	4.51 a	0.00	0.00	0.00
Correlation (*r*)		-0.82	-0.67	-0.98	-0.97	-0.61	NS	NS

[z] Determined with NIR System, from table 4.10.
[y] Means in columns with the same letter are not significantly different according to the LSD at $P \leq 0.05$ ($n = 9$).

The correlation between the force (N) and the relative density of the skin were negatively correlated *r* = -0.97. Periderm thickness was positively correlated with the force (N) *r* = 0.65. The number of cell layers in the periderm was positively correlated with the force (N) *r* = 0.69. In addition, the cell height was positively correlated with the force *r* = 0.95, and cell wall thickness was significantly correlated with the force where *r* = 0.94. Lignin content was well correlated with the force *r* = 0.66, while ash and calcium content were not significantly correlated (Table 4.13).

Table 4.13 Correlation between force needed with the force gauge to fracture the skin and the structural and chemical components of sweetpotato storage root of six cultivars at harvest.

Cultivars	Force (N)[z]	Relative density of skin (g·cm-3)	Periderm thickness (µm)	Number of Cell layers in Periderm	Cell height (µm)	Cell wall thickness (µm)	Lignin content (g·kg)[y]	Ash (g·kg)	Ca (g·kg)
"Covington"	1.66 a[x]	0.140 b	225.88 a	8.66 a	35.12 a	5.73 a	177.8 a	87.8 c	33.98 a
"Beauregard-63"	1.22 c	0.143 b	222.78 a	8.66 a	29.64 a	4.98 a	143.23 c	127.32 ab	36.02 a
"L07-146"	1.00 ef	0.145 ab	218.54 ab	7.83 ab	29.15 ab	4.96 a	158.43 b	90.26 bc	33.20 a
"Beauregard-14"	1.14 d	0.145 ab	189.29 abc	8.5 ab	28.93 ab	4.9 a	156.13 b	100.18 bc	35.30 a
"Hatteras"	1.03 de	0.146 a	155.6 bc	8.5 ab	26.86 b	4.61 a	158.53 b	120.72 abc	35.72 a
"Jewel"	0.90 f	0.148 a	143.63 c	7.83 ab	25.88 b	4.51 a	0.00	0.00	0.00
Correlation (*r*)		-0.97	0.65	0.69	0.95	0.94	0.66	-0.36	-0.17

[z] From table 4.3.

[y] Determined with NIR System, from table 4.10.

[x] Means in columns with the same letter are not significantly different according to the LSD at $P \leq 0.05$ (n = 9).

The correlation between the pressure (kPa) needed to fractures the skin and the density of skin, periderm thickness, number of cell layers in the periderm, were not significantly correlated. Cell height was negatively correlated with the pressure, r = -0.31. In addition, lignin content was negatively correlated with the pressure, r = -0.69. Ash content was well correlated with the pressure ejected by the skinometer, r = 0.53. In addition, calcium content was well correlated with the pressure, r = 0.71 (Table 4.14).

Table 4.14 Correlation between pressures needed to fracture the skin with the skinometer and the structural and chemical components of sweetpotato storage root of six cultivars at harvest.

Cultivar	**Pressure (kPa)[z]**	**Relative density of skin (g·cm-3)**	**Periderm thickness (µm)**	**Number of Cell layers in Periderm**	**Cell height (µm)**	**Cell wall thickness (µm)**	**Lignin content (g·kg)[y]**	**Ash (g·kg)**	**Ca (g·kg)**
"Covington"	565.4 c[x]	0.140 b	225.88 a	8.66 a	35.12 a	5.73 a	177.8 a	87.8 c	33.98 a
"Beauregard-63"	761.9 a	0.143 b	222.78 a	8.66 a	29.64 a	4.98 a	143.23 c	127.32 ab	36.02 a
"L07-146"	548.1 c	0.145 ab	218.54 ab	7.83 ab	29.15 ab	4.96 a	158.43 b	90.26 bc	33.20 a
"Beauregard-14"	741.2 a	0.145 ab	189.29 abc	8.5 ab	28.93 ab	4.9 a	156.13 b	100.18 bc	35.30 a
"Hatteras"	582.6 c	0.146 a	155.6 bc	8.5 ab	26.86 b	4.61 a	158.53 b	120.72 abc	35.72 a
"Jewel"	698.5 b	0.148 a	143.63 c	7.83 ab	25.88 b	4.51 a	0.00	0.00	0.00
Correlation (*r*)		NS	NS	NS	-0.31	-0.32	-0.69	0.53	0.71

[z] From table 4.4.
[y] Determined with NIR System, from table 410.
[x] Means in columns with the same letter are not significantly different according to the LSD at $P \leq 0.05$ ($n = 9$).

The correlation between the torque and the relative skin density were well-correlated, $r = 0.91$. Periderm thickness was well correlated with the torque, $r = 0.65$. The number of cell layers in the periderm were well correlated with the torque, $r = 0.76$. Cell height was well correlated with the torque with a coefficient of $r = 0.87$. Cell wall thickness was well correlated with the torque, r = 0.85. Calcium content had a negative correlation with the torque needed to break the skin. In addition, lignin content, ash, and dry matter were not significantly correlated to the torque (Table 4.15).

Table 4.15 Correlation between torques needed to fracture the skin with the torquometer and the structural and chemical components of sweetpotato storage of six cultivars at harvest.

Cultivars	Torque (N·m)[z]	Relative density of skin (g·cm-3)	Periderm thickness (µm)	Number of Cell layers in Periderm	Cell length (µm)	Cell wall thickness (µm)	Lignin content (g·kg-1)[y]	Ash (g·kg-1)	Ca (g·kg-1)
"Covington"	0.210 a[x]	0.189 b	225.88 a	8.66 a	35.12 a	5.73 a	177.8 a	87.8 c	33.98 a
"Beauregard-63"	0.196 abc	0.194 b	222.78 a	8.66 a	29.64 a	4.98 a	143.23 c	127.32 ab	36.02 a
"L07-146"	0.166 c	0.197 ab	218.54 ab	7.83 ab	29.15 ab	4.96 a	158.43 b	90.26 bc	33.20 a
"Beauregard-14"	0.175 cb	0.196 ab	189.29 abc	8.5 ab	28.93 ab	4.9 a	156.13 b	100.18 bc	35.30 a
"Hatteras"	0.173 cb	0.198 a	155.6 bc	8.5 ab	26.86 b	4.61 a	158.53 b	120.72 abc	35.72 a
"Jewel"	0.166 c	0.201 a	143.63 c	7.83 ab	25.88 b	4.51 a	0.00	0.00	0.00
Correlation (r)		0.91	0.65	0.76	0.87	0.85	NS	NS	-0.69

[z] From table 4.5.

[y] Were determined with NIR System, from table 4.10.

[x] Means in columns with the same letter are not significantly different according to the LSD at $P \leq 0.05$ ($n = 9$).

A negative correlation between the pressure and the relative skin density was observed, r = -0.83. Periderm thickness was well correlated with the pressure, r = 0.80. The number of cell layers was not significantly correlated with the pressure. The cell height was well correlated with the pressure r = 0.90. Cell wall thickness was well correlated with the pressure r = 0.92. Lignin content was well correlated with the pressure with a coefficient of r = 0.70. Ash content was negatively correlated with the pressure ejected by the Instrom r = -0.85. Calcium content was negatively correlated with the pressure, r = -0.79 (Table 4.16).

The relative density of special ultra-low density materials like foams ρ = 0.001g·cm-3, cork ρ = 0.14 g·cm-3, and softwoods ρ = 0.15 - 0.40 g·cm-3 was previously reported by one study (Lukkassen and Meidell, 2007). The relative density of the potato tuber parenchyma is estimated as ρ = 0.010 g·cm-3 (Gibson, 2012). In this study, it was found that the density of the skin of the sweetpotato storage roots at harvest was significantly different for cultivar “Jewel”, and “Hatteras” with a density of ρ = 0.148 g·cm-3 ,and density of ρ = 0.146 g·cm-3, respectively. The densities from all cultivars were in the range 0.140 to 0.148 g·cm-3; this data is similar to the natural cork 0.140 g·cm-3 .

Table 4.16 Correlation between pressures needed to fracture the skin with the Instrom and the structural and chemical components of sweetpotato storage root of six cultivars at harvest.

Cultivars	Pressure (kg·cm-2)	Relative density of skin (g·cm-3)	Periderm thickness (µm)	Number of Cell layers in Periderm	Cell height (µm)	Cell wall thickness (µm)	Lignin content (g·kg)[y]	Ash (g·kg)	Ca (g·kg)
"Covington"	24.71 a[x]	0.140 b	225.88 a	8.66 a	35.12 a	5.73 a	177.8 a	87.8 c	33.98 a
"Beauregard-63"	22.48 cb	0.143 b	222.78 a	8.66 a	29.64 a	4.98 a	143.23 c	127.32 ab	36.02 a
"L07-146"	23.68 ab	0.145 ab	218.54 ab	7.83 ab	29.15 ab	4.96 a	158.43 b	90.26 bc	33.20 a
"Beauregard-14"	22.82 cb	0.145 ab	189.29 abc	8.5 ab	28.93 ab	4.9 a	156.13 b	100.18 bc	35.30 a
"Hatteras"	21.57 c	0.146 a	155.6 bc	8.5 ab	26.86 b	4.61 a	158.53 b	120.72 abc	35.72 a
"Jewell"	21.86 c	0.148 a	143.63 c	7.83 ab	25.88 b	4.51 a	0.00	0.00	0.00
Correlation (*r*)		-0.83	0.80	NS	0.90	0.92	0.70	-0.85	-0.79

[z] From table 4.6.
[y] Were determined with NIR System, from table 4.10.
[x] Means with the same letter are not significantly different according to the LSD at $P \leq 0.05$ (n = 9).

57

In a previous study on cell wall mechanics and growth, the cell walls of the plants had at least two integrated load-bearing components, Ca^{2+} -pectate, and cellulose (Paucelle A., Braybrook S., and H. Höfte, 2012). Another study showed that there is a positive correlation between skin adhesion and cell wall enzyme activity. In addition, lignin was not related to skin adhesion (Villavicencio L. et al, 2007).

Experiment III. Evaluating preharvest cultural practices to enhance sweetpotato storage root skin set.

Results indicated that the highest lignin content resulted with ethephon at 1.68 Kg·ha-1 7 days before harvest (642 pµm) and 3 days before harvest (618.0 pµm) respectively. The secound highest measurament of lignin content resulted from Ethephon at the rate of 1.68 kg·ha-1 applied three days before harvest, (618.0 pµm). When plants were devined at seven days and three days before harvest, lignin content did not differ compared to lignin content of plants treated with ethephon at the rate of 0.84 kg·ha-1 one day before harvest. Lignin content were (339.6 pµm), (377.7 pµm), and (386.8 pµm), respectively. The lowest lignin content observed result from devining one day before harvest, and the control with the lignin content (176.3 pµm and 160.2 pµm) respectively (Table 4.17).

Table 4.17 The effect of preharvest treatments on lignin content of cultivar "Beauregard-14", sweetpotato storage roots observed by fluorescent microscope at harvest.

Treatments	**Lignin content (pµm)[z]**
Control	160.2 d
Devinning 1 day before harvest	176.3 d
Devinning 3 days before harvest	339.6 c
Devinning 7 days before harvest	377.7 c
Ethephon 0.84 Kg/ha 1 day before harvest	386.8 c
Ethephon 0.84 Kg/ha 3 days before harvest	423.9 b
Ethephon 0.84 Kg/ha 7 days before harvest	430.5 b
Ethephon 1.68 Kg/ha 1 day before harvest	445.2 b
Ethephon 1.68 Kg/ha 3 day before harvest	618.0 a
Ethephon 1.68 Kg/ha 7 day before harvest	642.0 a

[z] Means with the same letter are not significantly different according to Tukey evaluation at ≤ 0.05 (n = 9).

Ethephon at the rate of 0.84 kg·ha-1 applied three days and one day before harvest and devining three days before harvest resulted in the highest lignin content, according to NIR analysis with 167.63 g·kg-1, 163.50 g·kg-1, and 163.66 g·kg-1 of lignin content respectively. The lowest lignin content observed was in the control with 140.30 g·kg-1 (Table 4.18).

Table 4.18 The effect of preharvest treatments on lignin content of the cultivar "Beauregard-14", sweetpotato storage roots observed by NIR at harvest.

Treatments	**Lignin content (g/Kg)[z]**
Control	140.30 c
Devinning 1 day before harvest	157.86 b
Devinning 3 days before harvest	163.66 a
Devinning 7 days before harvest	152.53 b
Ethephon 0.84 Kg/ha 1 day before harvest	163.50 a
Ethephon 0.84 Kg/ha 3 days before harvest	167.63 a
Ethephon 0.84 Kg/ha 7 days before harvest	151.70 b
Ethephon 1.68 Kg/ha 1 day before harvest	150.26 b
Ethephon 1.68 Kg/ha 3 day before harvest	150.63 b
Ethephon 1.68 Kg/ha 7 day before harvest	159.50 b

[z]Means with the same letter are not significantly different according to Tukey's evaluation at ≤ 0.05 ($n = 9$).

Shear stress plus tensile stress taken with the torquometer showed that ethephon applied at a rate of 1.68 Kg·ha-1 three days before harvest resulted in the highest torque needed to fracture the skin. The lowest stress resulted from devining one day before harvest and control with 2.18 N•m, and 2.17 N•m, respectively (Table 4.19).

Ethephon at rate of 1.68Kg·ha-1 applied seven days before harvest had the highest observation for the fracture of the skin measured by the force gauge with 2.99 N. (Table 4.20).

Table 4.19 The effect of preharvest treatments on tensile stress plus the shear stress measured with the torquometer on the skin of cultivar "Beauregard-14", sweetpotato storage roots at harvest.

Treatments	**Torque (N•m)[z]**
Control	2.17 c
Devinning 1 day before harvest	2.18 c
Devinning 3 days before harvest	2.88 b
Devinning 5 days before harvest	2.58 b
Devinning 7 days before harvest	2.26 b
Ethephon 1.68 Kg/ha 1 day before harvest	2.76 b
Ethephon 1.68 Kg/ha 3 day before harvest	3.23 a
Ethephon 1.68 Kg/ha 5 day before harvest	2.85 b
Ethephon 1.68 Kg/ha 7 day before harvest	2.85 b

[z]Means with the same, not same letter are not significantly different according to Tukey's evaluation at ≤ 0.05 (n = 9).

Table 4.20 The effect of pretreatments on tensile stress plus the shear stress measured with the force gauge on the skin of cultivar "Beauregard-14", sweetpotato storage roots at harvest.

Preharvest treatments	**Force (N)[z]**
Control	1.46 c
Devinning 1 day before harvest	1.56 c
Devinning 3 days before harvest	1.72 c
Devinning 5 days before harvest	2.07 b
Devinning 7 days before harvest	2.35 b
Ethephon 1.68 Kg·ha-1 1 day before harvest	1.91 c
Ethephon 1.68 Kg·ha-1 3 day before harvest	2.42 b
Ethephon 1.68 Kg·ha-1 5 day before harvest	2.4 b
Ethephon 1.68 Kg·ha-1 7 day before harvest	2.99 a

[z] Means with the same not same letter are not significantly different according to Tukey's evaluation at ≤ 0.05 (n = 9).

Ethephon at rates 1.68 Kg·ha-1, and 0.84 kg·ha-1 at seven days before harvest, and devining three and seven days before harvest resulted the highest spin density in the skin of storage roots, 1.737 g·cm-3, 1.420 g·cm-3, 1.240 g·cm-3, and 1.011 g·cm-3 , respectively. The lowest skin density was observed with the control (Table 4.21).

Table 4.21 The effect of preharvest treatments on cell wall density observed with the fluorescent microscopy on the skin of sweetpotato cultivar “Beauregard-14”, storage roots at harvest.

Preharvest treatments	**Density (g·cm-3)^{z}**
Control	0.28 c
Devinning 1 day before harvest	0.31 c
Devinning 3 days before harvest	1.24 a
Devinning 7 days before harvest	1.01 a
Ethephon 0.84 Kg·ha-1 1 day before harvest	0.45 c
Ethephon 0.84 Kg·ha-1 3 days before harvest	0.65 b
Ethephon 0.84 Kg·ha-1 7 days before harvest	1.42 a
Ethephon 1.68 Kg·ha-1 1 day before harvest	0.80 b
Ethephon 1.68 Kg·ha-1 3 days before harvest	0.85 b
Ethephon 1.68 Kg·ha-1 7 days before harvest	1.73 a

^{z}Means with the same not same letter are not significantly different according to Tukey’s evaluation at ≤ 0.05 (n = 9).

The application of preharvest treatments to enhance skin toughness have been in use since 1967 when researchers used chemical herbicides, and vines cut to ground level. Such practices applied 10 to 30 days before harvest significantly enhanced skinning resistance at harvest (Austin and Graves, 1970). Another study found that skin damage was reduced by 62% when vines were removed 10 day before harvest, 53%, when they were removed eight days before harvest, and 26% when they were removed 4 days before harvest compared to when devining was done at harvest (LaBonte and Wright, 1993).

Skin set was studied with the use of preharvest treatments applying chemicals desiccant herbicides, and vine detachment; it was found that torquometer was sensitive enough to determine the differences between treatments. Secondly, that devining seven day before harvest resulted in the highest torque needed to produce the rupture of the skin in the storage roots of sweetpotato (Jett, 1999).

Other studies described and used the preharvest treatments for vine detachment in potato crop to promote skinning toughness and increase in harvesting efficiency (Smith and Wright M, 1994).

In other study with the skinometer, it was observed that preharvest treatments appeared to be more important, since preharvest application two weeks versus one week was effective in hardening the skin (Schultheis et al., 2000). However, the preharvest treatment application had the risk of affecting sweetpotato storage roots in other ways, such as greater tip rot of storage roots treated with high rates of ethephon (Arancibia and Main, 2010).

Exposure of sweetpotato storage roots to ethylene had to be avoided during storage or handling. When storage roots were exposed to ethylene in storage conditions,

ethylene increased the levels of peroxidase, catecholase, and phenolics. Discoloration and development of off-flavors in baked sweetpotato storage roots were related to the high levels of phenolic, and phenolic oxidizing enzymes (Buesher et al., 1975).

In this study, the application of ethephon and devining at seven days before harvest increased lignin content, and skin resistance to peeling. The torquometer registered the highest values when ethephon was applied three days before harvest. The force gauge registered the highest reading when ethephon was applied seven days before harvest. Higher cellular density was observed when ethephon was applied at three and seven days before harvest. In addition, within the period of three and seven days before harvest the preharvest treatments increased cell wall thickness and cellular density.

Experiment IV. Evaluating changes in skin characteristics due to curing and without curing of sweetpotato storage roots.

Non-curing seven day after harvest resulted in the lowest lignin content of 318.3 pµm, and the curing seven days after harvest resulted in the highest lignin content of 368.3 pµm as observed with the fluorescent microscopy (Table 4.22).

Non-curing for seven days, resulted in the following; the cultivar "Beauregard-63" had a torque of 0.29 N•m, which was the highest result followed by cultivars. "Evangeline" with 0.26 N•m and "Beauregard-14" with 0.23 N•m. Curing for seven days resulted cultivar "Beauregard-63"with a torque of 0.31 N•m, which was the highest resistance to shear and tensile stress. Followed by "Evangeline" with 0.31 N•m. The lowest resistance to fracture of the skin was observed in cultivars "Covington" with 0.29 N•m, "Centennial" with 0.221 N•m, and "Jewell" with 0.216 N•m. The treatment curing

for seven days after harvest was effective for all cultivars. The curing treatment enhances the toughness for all cultivars (Table 4.23).

Table 4.22 Effect of curing on the lignin content observed with the fluorescent microscopy in cultivar "Beauregard-14".

Treatments	**Mean (pµm)[z]**
Curing 7 days	368.3 a
Curing 3 days	340.1 b
Non-curing 7 days after harvest	318.3 c

[z]Means with the same letter are not significantly different according to the Tukey's evaluation at $P \leq 0.05$ ($n = 9$).

Table 4.23 Skin resistance to shear and tensile forces in sweetpotato storage roots at harvest, after curing and non-curing for seven days as determined by the torquometer.

Cultivar	At harvest. Torque (N·m)	Non-curing seven days after harvest. Torque (N·m)	Curing seven days after harvest. Torque (N·m)
"Beauregard-63"	0.21 a	0.29 a	0.31 a
"Beauregard-14"	0.19 bc	0.23 c	0.31 a
"Evangeline"	0.20 b	0.26 b	0.31 a
"Hatteras"	0.16 c	0.24 c	0.29 a
"Jewell"	0.17 c	0.22 d	0.29 a
"Covington"	0.17 c	0.22 d	0.29 a
"Centennial"	0.16 c	0.22 d	0.26 a
Treatment effect	0.18 c	0.24 b	0.29 a

[z]Means in the columns with the same letter are not significantly different according to the Tukey's evaluation at $P \leq 0.05$ (n = 9).

At harvest, "Jewell" with 1.741 N, had the highest resistance to breaking of the skin by the force gauge. There was no significant difference in resistance to breaking of the skin among the remaining cultivars. The treatment results for non-curing for seven days after harvest had the cultivar "Beauregard – 63" with the highest resistance to fracture the skin 2.525 N. The cultivar "Jewell" needed a force of 2.279 N, "Hatteras" with a resistance to break the skin of 2.116 N, followed by the cultivar "Evangeline" with a result of force 2.089 N. The lower resistance to fracture the skin was obtained in cultivars "Beauregard-14" with a 2.024 N, and "Covington" with a 1.857 N.

“Centennial” had the lowest force 1.759 N. Results of curing for seven days were as follows; “Beauregard-63” had the greatest resistance to fracture the skin with a force of 2.867 N. Resistance to skin fracture did not differ among the remaining cultivars (Table 4.24).

Table 4.24 Skin resistance in sweetpotato roots to shear and tensile force at harvest, non-curing and curing for seven days as determined by the force gauge.

Cultivars	At harvest. Force (N)	Non-curing seven days after harvest. Force (N)	Curing seven days after harvest. Force (N)
“Beauregard-63”	1.74 b	2.52 a	2.86 a
“Beauregard-14”	1.74 b	2.02 cd	2.56 b
“Evangeline”	1.70 b	2.08 c	2.55 b
“Hatteras”	1.67 b	2.11 bc	2.52 b
“Jewell”	1.77 a	2.27 b	2.50 b
“Covington”	1.652 b	1.857 d	2.49 b
“Centennial”	1.60 b	1.75 d	2.48 b
Treatment effect	1.69 c	2.092 b	2.57 a

^{z}Means in the columns with the same letter are not significantly different according to the Tukey’s evaluation at $P \leq 0.05$ (n = 9).

Results obtained confirmed the reports from different sources that curing usually improves skin toughness, and improved the skin adhesion, and the effect of curing was correlated with plant growth temperature (Boyette, et al., 1997; Villavicencio et al, 2007). Curing for seven days also reduced the incidence of tip and end rot of sweetpotato roots (Arancibia et al., 2013). When roots were exposed to high or low temperatures before curing, the percentage of disease infection increased (Nielsen, 1964). Curing also improved the culinary quality by increasing the amount of amylase, which converts starch to sugars during cooking (Picha et al., 2001).

Experiment V. Evaluation of anatomical changes during the wound healing process with and without curing.

Results showed that curing seven days plus wounding, resulted in the highest lignin content of the cultivars "Beauregard-14" had a lignin content of 479.10 pµm, "L07-146" had a lignin content of 657.50 pµm and "L07-6R" had a lignin content of 369.69 pµm. Curing for three days resulted with intermediate lignin content. Cultivar "Beauregard-14" had a lignin content of 340.10 pµm, cultivar "L07-146" had a lignin content of 362.00 pµm, and cultivar "L07-6R" had a lignin content of 225.12 pµm.

The control seven days without curing had the lowest content, followed by "Beauregard-14" with a lignin content of 318.30 pµm, "L07-146" with a lignin content of 470.00 pµm, and "L07-6R" with a lignin content of 247.69-pµm.

The sweetpotato roots cured for seven days had the lignin content higher than non-curing for seven days. Results showed that "Beauregard-14" had a lignin content of 368.30 pµm, "L07-146" had a lignin content of 486.50 pµm, and cultivar "L07-6R" had a lignin content of 313.18 pµm.

The wounding treatments for three days and non-curing resulted in the lowest lignin content (Table 4.25).

Table 4.25 Effect of curing on wound healing and lignin content of three sweetpotato cultivars determined by the fluorescent microscopy.

Treatments	"Beauregard-14" (pµm)	"L07-146" (pµm)	"L07-6R " (pµm)
Cuirng 7 days wounding	479.10 a[z]	657.50 a	369.69 a
Curing 7 days	368.30 b	486.50 b	313.18 ab
Non-curing 7 days	318.30 d	470.00 c	247.69 bc
Curing 3 days	340.10 c	362.00 d	225.12 bc
Curing 3 days wounding	281.40 e	311.90 e	263.62 abc
Wounding 3 days non-curing	256.40 f	239.60 f	211.63 c

[z]Means in columns with the same letter are not significantly different according to Tukey's evaluation at $P \leq 0.05$ ($n = 9$).

Table 4.26 shows cell wall thickness for three cultivars as influenced by curing treatment.in Cultivar "L07-146" had the lowest cell wall thickness with 8.33 µm when curing for 3-days. The transition area had cell wall thickness of 11.78 µm. No differences were observed between the treatments, curing 3-days wounded, and curing seven days without wounded. Curing 7 days within transition area, and curing 7-days wounded, resulted in greater cell wall thickness of 17.33 µm, and 18.89 µm, respectively. The cultivar "L07-146" showed for the cell length the lowest results. The following

treatments; curing 3-days native skin, and curing 3-days transition area, 39.64 µm, and 39.48 µm, respectively. The other treatments had no significantly difference.

Cultivar “Beauregard-14” had the lowest cell wall thickness with curing for 3 days with 6.74 µm, followed by the treatment curing 3-days transition area with 11.05 µm. The treatments curing 3 days wounded, curing seven days without wounded and curing 7-days transition area were not significantly different. The treatment curing 7 days wounded area had the highest results in cell wall thickness with 19.41 µm. The cell length had the lowest results with the treatment of curing 3-days native skin 26.48 µm. The highest cell length was observed with treatment curing 7-days wounded area with 68.05 µm.

Data for cell length and the cell wall thickness are well correlated. The correlation coefficient were as follows: “L07-146” with $r = 0.84$, the cultivar “L07-6R” with $r = 0.59$ and the cultivar Beauregard-14 with $r = 0.78$ (Table 4.26).

Table 4.26 Effect of curing during different period over the physical parameters of the cell skin storage sweetpotato roots in three cultivars

Cultivars	"L07-146"		"L07-6R"		"Beauregard-14"	
Treatment	**Cell wall thickness**	**Cell length**	**Cell wall thickness**	**Cell length**	**Cell wall thickness**	**Cell length**
Curing 3-days native skin	8.33 b	39.64 b	7.07 b	29.75 b	6.74 c	26.48 c
Curing 3-days transition area	11.78 b	39.48 b	5.72 b	29.67 b	11.05 b	49.85 b
Curing 3-days wounded area	16.74 ab	62.42 a	8.44 ab	72.37 a	15.51 ab	62.79 ab
Curing 7-days native skin	15.83 ab	75.50 a	9.89 ab	70.14 a	14.89 ab	33.55c
Curing 7-days transition area	17.33 a	65.95 a	28.12 a	69.52 a	13.98 ab	53.07 ab
Curing 7-days wounded area	18.89 a	76.10 a	28.23 a	73.02 a	19.41 a	68.05 a
Correlation (*r*)	0.84		0.59		0.78	

[x]Means in the columns with the same letter are not significantly different according to the Tukey at $P \leq 0.05$ (n = 9).
[y]Native skin = non-wounded skin.
[z]Transition area = between the wounded and native skin

Figure 4.6, shows the morphological description of the skin in “L07-6R”. Figure 4.6-A, shows the native skin at three days of curing. The phellem cell layers observed were completely lignificated. The number one inside the circle indicates the phellem tissue located on the outer side of the skin. The phellem tissue appears dehydrated. Three days of curing resulted in thinner cell walls with a thickness of 8.33 µm, and cell length of 39.64 µm, (Table 4.26). The native skin is mostly formed by the phellem. It is slightly dehydrated, flattened, and misshapen. The number two indicates the cell layers of phellogen and shows the cell wall without lignification. The phellogen is a living tissue with stable cells, which multiply when receiving external stimulus to do so. The number

three is pointing at the phelloderm, at the inner tissue of the skin. Figure 4.6-B, shows the affected area and the healing process of curing for 3-days observed at the transition area from the native skin to the wounded area, inside the dotted circle. It shows the lower measurement for cell wall thickness 11.78 µm, and cell length 39.48-µm. Figure 4.6-C, the measurement obtained from the wounded area shows the cell wall thickness of 16.4µm at the outer side, and cell length of 62.42 µm. The number two identifies the phellogen tissue.

Figure 4.6-D, shows the native skin highly hydrated with respect to the 3 days curing treatment. The measurement obtained for cell wall thickness, 15.83 µm, and cell length, 75.50 µm were not significantly different from cell wall thickness and cell length obtained with the treatment for 3 days curing. However, the native skin or the phellem is seen completely lignificated, hydrated and turgid, and the cell walls standing in right position in full function. Figure 4.6-E shows the transition area of the native skin, the cell wall thickness of 17.33 µm, and cell length of 65.95 µm with are significantly higher than the measurement from the native skin for the same treatment. Figure 4.6-F shows the curing and healing process at the wounded area with a cell wall thickness of 18.89 µm, and cell length of 76.10 µm, which were significantly higher than the treatment with 3 days curing for the cultivar L07-6R.

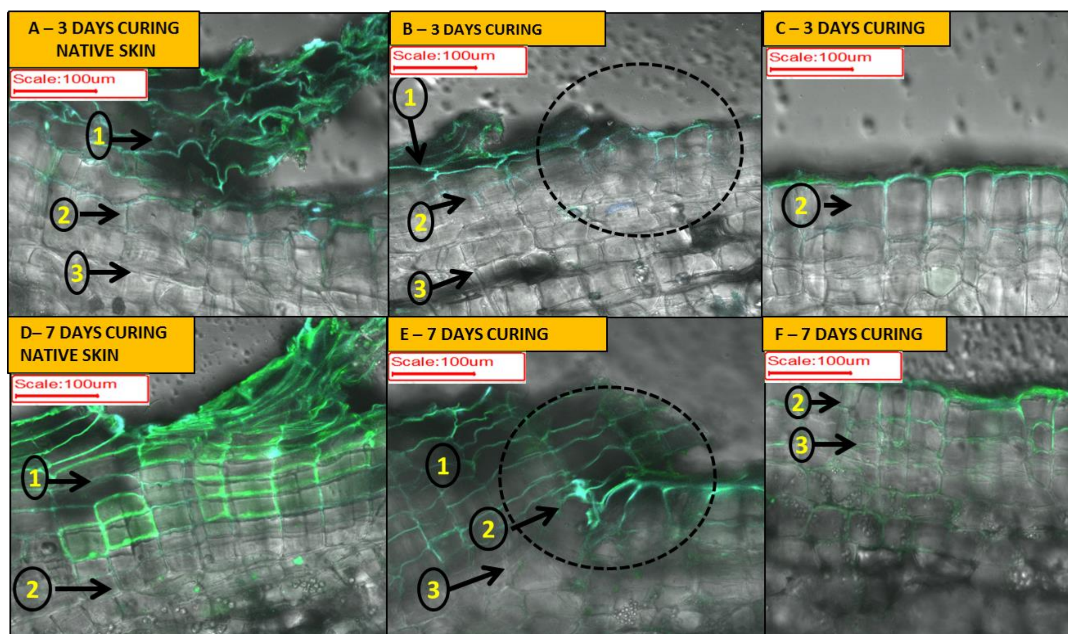

Figure 4.6 Microphotographs of sweetpotato root skin tissue showing different phases of curing and healing taken with the fluorescent light with the confocal microscopy to the periderm of storage roots of sweetpotato, cultivar "L07-6R".

A) Showed the lignificated cell layers of the phellem slightly dehydrated, compressed and deformed. B) Shown inside of the dotted circle the transition area between the periderm and the wounded area. C) Shown the wounded are. D) Showed the lignificated cell layers of the phellem high hydrated. E) Shown inside of the dotted circle the transition area between the periderm and the wounded area. F) Wounded area.

Figure 4.7, shows the morphological description of the skin in cultivar "L07-146". Figure 4.7-A, shows the native skin at three days of curing. The phellem cell layers are observed completely lignificated, the number 1 inside the circle points at the phellem tissue at the outer side of the skin. Three days of curing resulted in thinner cell wall with a thickness of 7.07 µm, and cell length of 29.75 µm (Table 4.26). The native skin, mostly formed by the phellem, is completely lignificated, to some extent dehydrated, compressed, and deformed. The cell walls are breaking up, and the cell turgor is down; the number 2 is pointing to the cell layers of phellogen; the cell wall without lignification

is observed. The phellogen is a living tissue with stable cells, which multiply when receiving external stimulus. The number 3 points the phelloderm at the inner of the skin. In figure 4.7-B, shows the affected area and the healing process of the curing 3 days treatment that resulted in the lower measurement for the cell wall thickness of 5.72 µm, and the cell length of 29.67 µm. Such values were slightly lower than the measurement obtained from the native skin. Figure 4.7-C, shows the wounded area. The measurement obtained from the wounded area show a cell wall thickness at the outer side of 8.44 µm, and cell length of 72.37 µm. The healing process is proof of the damage tissue. The number 2 on the microphotograph identifies phellogen tissue.

Figure 4.7-D, shows the native skin highly hydrated respect to the appearance of tissue resulting from 3 days curing treatment. Cell wall thickness of 9.89-µm and cell length of 70.14 µm were not significantly different from cell wall thickness and cell length obtained with 3-days curing. However, the native skin or the phellem is observed completely hydrated and turgid and the cell walls standing in the right position in full function. Figure 4.7-E shows the transition area from the native skin with a cell wall thickness of 28.12 µm, and cell length of 69.52 µm, which are significantly greater than the results of curing for 3 days. The figure 4.7-F shows the curing and healing process at the wounded area; the cell wall thickness of 28.23 µm, and cell length of 73.02 µm were significantly greater compared with the results of curing for 3 days in cultivar “L07-146”.

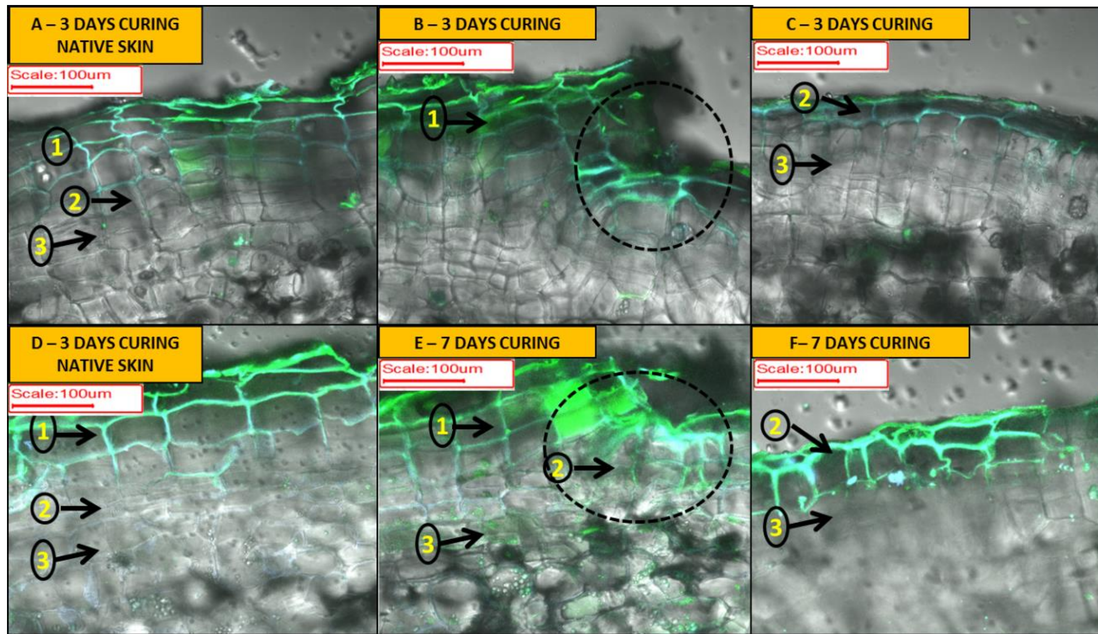

Figure 4.7 Microphotographs of sweetpotato root skin tissue showing different phases of curing and healing process takes with the fluorescent light with the confocal microscopy into the periderm of the storage roots of sweetpotato "L07-146".

A) Showed the lignificated cell layers of the phellem slightly dehydrated, compressed and deformed. B) Shown inside of the dotted circle the transition area between the periderm and the wounded area. C) Shown the wounded are. D) Showed the lignificated cell layers of the phellem high hydrated. E) Shown inside of the dotted circle the transition area between the periderm and the wounded area. F) Wounded area.

Figure 4.8 shows the morphological description of the skin in cultivar "Beauregard-14". Figure 4.8-A, shows the native skin at three days of curing. The phellem cell layers are observed completely lignificated; number one inside the circle in pointing at the phellem tissue at the outer side of the skin. Its expressions are slightly shriveled. The treatment for three days of curing performed the lower observation in the cell wall thickness 6.74 µm, and cell length 26.48 µm (Table 4.26). The native skin is mostly formed by the phellem. It is slightly dehydrated, flattened, and misshapen. The cell walls are breaking up, and the cell turgidity is down; the number two is pointing the

cell layers of Phellogen. The cell wall is observed without lignification. The phellogen is an active tissue. The number 3 is pointing out the phelloderm at the inner of the skin. Figure 3.8-B, shows the affected area and the healing process of the treatment curing 3-days observed at the transition area from the native skin to the wounded area, inside the dotted circle. It had shown the higher measurement for cell wall thickness 11.05 µm, and cell length 49.85 µm, than the treatment at the native skin, but they are not significant different. Figure 4.8-C, shows the wounded area, where the healing process is observed at the cell wall at the outer side. The measurement obtained from the wounded area shows a cell wall thickness at the outer side with 15.51 µm, and cell length with 62.79 µm. They are significantly different in respect to the two treatments at 3 days curing. The sealing process is in the proof of the damage tissue; the outer cell wall is thickening. The number two indicates the phellogen tissue. In contrast, the treatment for 7 days curing figure 4.8 D, shows the native skin highly hydrated respect due to the 3-days curing treatment. The measurement obtained for the cell wall thickness 14.89 µm, and the cell length 33.55 µm. The native skin or the phellem is observed completely hydrated and turgid, the cell walls standing in right position in full function. Figure 4.8-E shows the transition area from the native skin, the cell wall thickness with 13.98 µm, and cell length 53.07 µm significantly higher than the measurement from the treatment curing 7 days native skin. Figure 4.8-F shows the curing and healing process at the wounded area, the cell wall thickness 19.41 µm, and cell length 68.05 µm were significantly higher than the treatment with 7 days curing native skin, and curing 3 days treatments for the cultivar “Beauregard-14”.

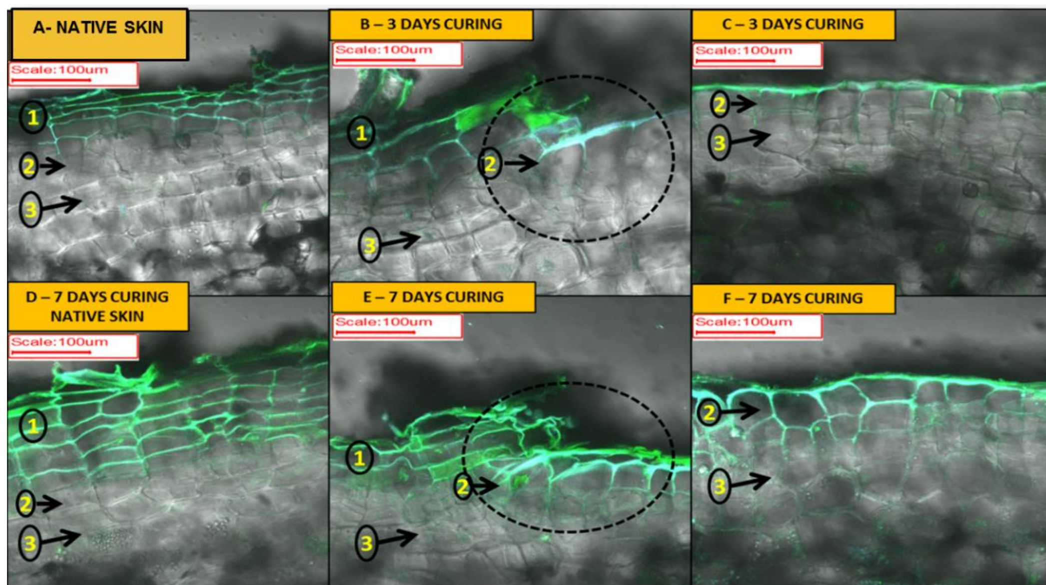

Figure 4.8 Microphotographs of sweetpotato root skin tissue showing different phases of curing and healing process takes with the fluorescent light with the confocal microscopy into the periderm of the storage roots of sweetpotato cultivar "Beauregard-14".

A) Showed the lignificated cell layers of the phellem slightly dehydrated, compressed and deformed. B) Shown inside of the dotted circle the transition area between the periderm and the wounded area. C) Shown the wounded area. D) Showed the lignificated cell layers of the phellem high hydrated. E) Shown inside of the dotted circle the transition area between the periderm and the wounded area. F) Wounded area.

The cultivar Beauregard-14, showed the following results; for the cell length which had the highest significant difference with the treatment non-curing for three days plus curing for three days of134.52 µm, and the treatment with curing for seven days and wounded with a cell length of 65.623 µm. The other treatments did not differ with respect to cell length. The highest results for cell thickness was obtained by curing seven days plus wounded with a cell thickness of 24.28 µm. Followed by curing for three days plus wounded with a cell thickness of 15.68 µm, and curing for seven days in the transition area between the native skin and wounded area with a cell thickness of 15.52 µm. The lower measurement was observed in three treatments, curing for seven days 8.59

µm, non-curing for seven days after harvest with 7.43 µm, and curing three days with 7.36 µm. The density of the skin was significantly highest when curing for 7 days and wounded with 0.0.425 g·cm-3, followed by curing for 7 days in the transition area with a skin density of 0.350 g·cm-3. The lowest measurement for skin density 0.086 g·cm-3 was observed with the treatment of non-curing for three days alternated with curing for three days.

Table 4.27 Cell length, cell thickness, and skin density of skin cell as influenced by curing.

Treatments	**Cell length (µm)**	**Cell thickness (µm)^z**	**Density (g·cm-3)^z**
Curing seven days wounded	65.623 b	24.28 a	0.425 a
Curing seven days transition area	50.88 bcd	15.52 b	0.350 ab
Curing three days wounded	60.29 bc	15.68 b	0.299 abc
Curing three days native skin	30.42 d	7.36 c	0.278 abc
Curing three days transition area	49.56 bcd	11.73 bc	0.272 abc
Curing seven days native skin	40.60 bcd	8.59 c	0.243 abc
Noncuring seven days after harvest native skin	38.17 cd	7.43 c	0.223 bc
Noncuring three days and curing three days	134.52 a	10.15 bc	0.086 c

^{z}Means in columns with the same letter are not significantly different according to the Tukey's evaluation at $P \leq 0.05$ (n = 9).

CHAPTER V

SUMMARY AND CONCLUSION

This study examined skinning which is responsible for the loss in quality appearance of sweetpotato storage roots during storage and in the fresh market. Skinning occurs when abrasive forces wound the periderm. The periderm is located at the surface area of the storage root, and it is composed of three types of tissues: phellem, phellogen, and phelloderm. The periderm fracture by exterior forces along a meristem cell layer, called phellogen, resulting in the separation of the phellem (outer cell layers) from the phelloderm, the inner cell layer. This surface scratch increases the risk of pathogen infection but also becomes visually unappealing. When a root is not properly cured after harvest, the skinned area becomes unappealing for consumption and marketability. The skinned condition can easily be confused with symptoms of surface rot or *Fusarium root* rot. Skinning wounds also provide a possibility for the ingress of many storage decay pathogens. However, the prevalence of postharvest diseases greatly increases by skinning, and the presence of spores, and microorganism in the dust from the field, and the lack of cleaned containers, and storage warehouses.

The objectives of this study were to; (1) determine the suitability of four instruments (Skinometer, Force gauge, Torquometer, and Instron) to measure skin toughness on periderm resistance in sweetpotato storage roots, and compare the resistance of the periderm with skin thickness differences among cultivars. (2) determine

periderm anatomical characteristics and chemical in the periderm of sweetpotato storage roots in seven cultivars, and associate periderm anatomical and chemical characteristics with skinning resistance, (3) determine the effect of preharvest strategies on skinning resistance in sweetpotato storage roots, (4) determine anatomical and chemical skin characteristics due to curing, and (5) characterize the healing process with and without curing. To fulfill these objectives, the following's five experiments described in the Materials and Methods section were conducted: Experiment 1. Determine the morphological differences and the breaking point of the periderm of sweetpotato storage roots with four mechanical testers. Experiment II. Anatomical characterization and lignin content in sweetpotato storage roots. Experiment III. Evaluating preharvest cultural practices to enhance the sweetpotato storage roots skin set. Experiment IV. Evaluate changes in skin characteristics due to curing and without curing of sweetpotato storage roots. Experiment V. Evaluated anatomical changes during the wound healing process with and without curing.

Cultivars "L07-6R" and "L07-146" had 12 and 10 cell layers in the periderm tissue. From the four skin testers, only the force gauge and the torquometer were the most accurate and precise in measuring the skin toughness. Cultivars "B-14", and "B-63" had the toughest skinned compared to the remaining cultivars when the torquometer and the force gauge were used.

Cultivars "L 07-6R", "L07-146", and "Beauregard -14" had the toughest skin. However, cultivars "Covington" and "Hatteras" had higher lignin content, which was highly correlated with the force and torque needed to break the skin.

Ethephon at 1.68 Kg·ha-1 three and seven days before harvest resulted in the higher lignin content as indicated with the fluorescent microscope. However, NIR analysis showed that divining at three days, Ethephon at 0.84 kg·ha-1 applied at one and three days before harvest resulted in the highest lignin content. Ethephon at 1.68 Kg·ha-1 applied at three and seven days before harvest resulted in the hardest skin as tested with the torquometer and the force gauge. Additional research to determine a precise rate and the number of days before harvest needed to apply the preharvest treatments is needs to be conducted.

Curing for seven days resulted in higher lignin content compared to the other curing treatments. At harvest, "Beauregard-63" had with the hardest skin, followed by "Evangeline", and "Beauregard-14".

The healing process was enhanced when wounded sweetpotato roots were cured for seven days. This indicated that sweetpotato roots have to be cured for at least seven day to avoid dehydration, and rot by pathogen attack in the wounded area of the roots due to mechanical injury at harvest.

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