ALPHA-AMYLASE AND SOLUBLE SUGARS IN TWO ZONES OF SWEETPOTATO ROOTS

A Thesis

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by
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DEDICATION

For Renato, Sérgio and André.

Your Love and Patience is Innumerable.

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ABSTRACT

Sweetpotato [*Ipomea batatas* (L)Lam] is consumed worldwide as a staple or complementary food. The nutritive value of processed sweetpotato products may be compromised by size exclusion and peeling and heat processing. This study investigated the distribution of alpha-amylase activity, alcohol insoluble solids (AIS), total sugars, maltose, sucrose, glucose, and fructose in two zones of 'Beauregard' and 'Jewel' sweetpotato roots. Previously cured (10 days at 30°C and 90% relative humidity), and stored (three and four months at 15°C and 85% relative humidity) roots were classified into two size categories (large, 6-9 cm and small, 2-4 cm diameter). The cambium of hand peeled roots was separated from the inner tissue, and each portion was ground and analyzed raw and after cooking (1 hr, 70°C). Analysis was performed by high performance liquid chromatography (HPLC) for sugars and spectrophotometry (alpha-amylase). The cambium of 'Beauregard' had significantly ($p<0.05$) more AIS and less sugars than the inner tissue. Conversely, 'Jewel' root cambium contained significantly less AIS and sugars than the inner tissue. Alpha-amylase activity was higher in 'Jewel' cambium but was not significantly different between the two zones of 'Beauregard'. Between cultivars, 'Beauregard' contained more alpha-amylase, sugars (except sucrose) and AIS than 'Jewel'. Overall, large roots contained less alpha-amylase than small roots but more maltose when heated. Cooking significantly reduced AIS and sucrose and increased maltose content. There was no significant variation in glucose and fructose content as a result of cooking. Four months storage yielded significantly higher alpha-amylase activity , AIS, and sucrose but less glucose and fructose than three months. These observations demonstrate that alpha-amylase activity and the

content of sugars are influenced by cultivar, storage, size, zone and cooking. It can also be inferred that the content of alpha-amylase in raw roots is not linearly related to maltose production during cooking.

INTRODUCTION

Sweetpotato [*Ipomoea batatas* (L.) Lam], grown in tropical and subtropical areas, is an important staple food source in many developing countries and is also consumed in some developed countries. The world production of sweetpotato roots was 124 x 10^6 metric tons in 1994. The largest world producer is China. Uganda is the most significant producer in Africa. The United States of America produced about 0.6 x 10^6 metric tons in 1994. Louisiana is the second largest sweetpotato producer in the United States, following North Carolina, with a total production of about 164 x 10^3 metric tons in 1995 (USDA, 1996; Picha and Hinson, 1996; FAO, 1994).

Sweetpotato roots, formed from young thick adventitious roots, have three main zones- the outermost zone, periderm, cork layer, or peel; the lacticifer cell exterior to the cambium plus the cambium, cortex or middle zone; and the innermost tissue, core zone (Noda *et al*, 1992; Walter and Schadel, 1982; Edmond and Ammerman, 1971; Groth, 1911). The characteristics of the zones depend on the cultivar, stage of development, and environmental conditions. The peel is the smallest zone. In young tubers, the cambium is reported to be larger than the inner tissue. In older tubers, it is the inner tissue that is the largest zone since it increases progressively with increasing tuber weight. The inner tissue starch content and granule size tend to be larger than those of the other zones. The cambium starches were reported to be the most susceptible to enzymatic action (Noda *et al.*, 1992). The leaves of the sweetpotato plant are an important source of protein, vitamins and minerals and the storage roots are rich in carbohydrates.

Due to the importance of sweetpotato as a source of carbohydrates and other nutrients, Louisiana State University (LSU), through Louisiana Agricultural Experiment Station (LAES) and Horticulture Department, has been researching the sweetpotato for many years. The research work includes agronomic practices, development of new cultivars, post-harvest physiology, and processing characteristics.

Several studies have shown that the physicochemical properties of sweetpotato roots vary with cultivar, root size, and environmental conditions during the cultivation, curing, storage and cooking. Enzymes, specifically alpha-amylase and beta-amylase, play an important role in the conversion of starch, the main constituent of sweetpotato roots, into soluble sugars. Any variation of enzyme concentration and conditions appears to affect the rheological properties of sweetpotato processed products, such as texture and moistness of flakes, and sweetness of puree and patties. Changes by zone were considered to contribute to the firmness reduction and sweetness increment of sweetpotato products (Morrison *et al.*, 1993; Walter and Hoover, 1984; Scott and Bouwkamp, 1975; Ikemiya and Deobald, 1966).

'Jewel' and 'Beauregard' were the two sweetpotato cultivars selected for this research. They are the most common commercial cultivars. 'Jewel' was developed in North Carolina and released in 1970. It is a high yield cultivar with attractive appearance. The roots are generally uniform with round shape in heavier soils, tapered on both ends, with a deep copper color skin and an orange flesh, and possess good processing and post-harvest qualities (Pope, 1970). 'Beauregard', released in 1987, is a cultivar developed by Louisiana Agricultural Experiment Station to combine resistance to diseases and insects

with good horticultural and culinary characteristics. The roots are fusiform to ovoid in shape, have a smooth and light rose skin, and a deep orange flesh (Rolston *et al.*, 1987). The sweetpotato represents about 59% of the production area of commercial vegetables in Louisiana and the 'Beauregard' cultivar represents about 98% of the sweetpotato production area (Picha and Hinson, 1996).

Size is a grading parameter, defined by diameter, length and weight. In the United States the standards of sizes for sweetpotato roots are defined by the United States Department of Agriculture (USDA) for commercial purposes (Boudreaux, 1996). Small roots are the preference for industry and medium roots for fresh market (Hoover *et al.*, 1983). Root size is considered to be related to chronological age of the roots, with large roots being older than small roots. Size may affect the enzyme activity, heat penetration, cooking, and carbohydrate composition of sweetpotato roots. In small roots the rate of heat penetration during cooking is higher than large roots (Mandava, 1995; Noda *et al,* 1995).

Curing and storage are important post-harvesting steps for sweetpotato roots. Curing hardens the peel, heals the wounds, reduces water loss, and reduces losses due to insect and microbial activity, as well. Storage extends the shelf life of harvested roots by maintaining their freshness as long as possible. During curing and storage the amylolytic enzymes reduce the alcohol insoluble solids (AIS) by conversion of starch, the major component of AIS, into soluble sugars depending on the duration and conditions of curing and storage (Winarno, 1992; Picha 1986b, 1986d; Hamann *et al.*, 1980; Walter *et al.*, 1975).

The enzyme distribution throughout the root tissues and its activity have been studied by some researchers, and their findings have shown variations in location and concentration of alpha- amylase by cultivar, length of storage, root size, and root zones of the sweetpotato. Ikemiya and Deobald (1966) reported that alpha- amylase was distributed almost uniformly throughout the inner tissues of 'Goldrush' root while beta-amylase was concentrated in the inner tissue. The optimum temperature for alpha- amylase activity was between 70°-75°C, and the maximum resistance to heat inactivation was at pH 6.0. Freshly harvested roots contained relatively smaller amounts of alpha- amylase. In contrast, Hagenimana *et al.* (1992a,b) worked with four cultivars, 'Jewel', 'Regal', 'White Delight', and 'Porto Rico', and they concluded that alpha- amylase was concentrated in the cambium or outer zone and was in very little concentration in the inner tissue whereas beta-amylase was distributed throughout the tuber. Alpha- amylase has been reported to increase with curing and storage resulting in the reduction of alcohol insoluble solids (AIS) and the production of soluble sugars (Walter *et al.*, 1975; Deobald *et al.*, 1969; Ikemiya and Deobald, 1966).

Carbohydrate composition in raw roots changes during curing and storage, and during cooking depending on method and conditions. Sweetness of cooked sweetpotato roots was found to be due to maltose content which was not found in raw roots (Mandava, 1995; Picha, 1986d, 1985; Reddy and Sistrunk, 1980). Starch content and alcohol insoluble solids (AIS) decreased during curing and storage, which may explain the increase of fructose, glucose, and total sugars during curing and storage. During cooking, sugar production increased as the internal temperature of the roots increased. The rate of starch

conversion into sugars was higher during the initial heating period. The content of non-reducing sugars was higher in raw roots than the reducing sugar fraction (Jenkins and Gierger, 1957). According to Deobald *et al.*(1969), the starch conversion into maltose ranged from 9% to 20%, dry basis, in raw grinds from sweetpotato roots stored for one to seven days at 16°C. Maltose concentration increased to about 42% after 30 to 60 minutes cooking at temperature between 75-78°C. At 95°C the enzymatic hydrolysis was reduced. In the same conditions there were no changes in sucrose and glucose contents with concentrations between 0.3-1.8% and 11-15%, respectively. In 'Jewel' stored for three months sucrose was the most abundant sugar in raw roots followed by glucose and fructose. Sucrose was the major sugar at harvest, and its concentration did not change during curing and storage. Glucose and fructose increased during curing and storage, with glucose in higher concentrations compared with fructose. The increase of individual or total sugars were related to starch hydrolysis (Picha, 1986b, 1985). The concentration of maltose in cooked roots was higher when the temperature was above 75°C (Deobald *et al.*, 1971; Sistrunk *et al.*, 1954).

The sweetpotato canning industry has preference for small roots and the fresh market prefers medium roots but the composition of large roots may represent high quality for processed products. The root peeling is done chemically or mechanically, removing not only the periderm but also the cambium. This may reduce the quality of the end products. Based on these assumptions, this present study was carried out to determine the composition of zones of different size roots.

The overall objective of this study is to evaluate the influence of cultivar, root size, and root zone on alpha-amylase activity and carbohydrate content in sweetpotato roots. The research was conducted with raw and cooked samples of the inner tissue and cambium of two different root sizes of 'Beauregard' and 'Jewel' stored for three and four months in order to: 1) determine the α-amylase activity; 2) determine the concentrations of various carbohydrate fractions including alcohol insoluble solids (AIS), total sugars, maltose, sucrose, glucose and fructose in raw and cooked roots; and 3) analyze the relationship between amylolytic enzymes and carbohydrates in sweetpotato cambium and inner tissue root zones.

This study is expected to provide useful information on physicochemical differences between zones of sweetpotato roots influenced by cultivar, storage, size, and processing, particularly on 'Beauregard', a newly developed cultivar with limited available information. The results on root size and zones on both cultivars will add information that may be useful for sweetpotato processors in terms of root selection and peeling, contributing to better product quality at lower costs.

REVIEW OF LITERATURE

OVERVIEW

The sweetpotato ((*Ipomea batatas*) Lam.L.) is a starchy crop, originally from the tropics, which is produced worldwide. It is a herbaceous species that belongs to Convolvulaceae family of Dicotiledonea group. Sweetpotato is a perennial plant but is grown as an annual crop for human and animal consumption, and for industrial purposes (Bradbury and Holloway, 1988). Current cultivars of this semiperishable crop can be grown in a wide range of soils and weather conditions, and possess resistance to pests and diseases. The crop does not require high levels of input and irrigation, yielding an average 9000 kg/hectare. The roots can be kept longer in the soil giving a flexible harvesting period. The harvested roots can be kept at natural conditions for long periods. It is propagated vegetatively by stem cuttings or by sprouted pieces of storage roots but can be also reproduced by seeds (Winarno, 1992; Ewel and Mutuura, 1991; Bouwkamp, 1985).

In the United States, sweetpotatoes are harvested from July to November, and storage makes this crop available potentially until the following harvest. However, the canning industry rarely processes after January because the roots lose firmness and easily disintegrate, lowering the quality of canned roots. The small roots have good market for the canning industry and the medium size roots for fresh market. Jumbo or large size and misshaped roots have no specific market (Hoover *et al.*, 1983), although they are often used for 'cuts' and mash packs. 'Jewel' and 'Beauregard' are currently the most widely grown cultivars for commercial purposes in the United States. They represent 90% of the total sweetpotato production. Both are cultivars preferred by the American consumers having

an internal orange color, with dry matter content up to 30% and, when cooked, having a high concentration of maltose (Boudreaux, 1996; Walter and Palma, 1996; Koehler and Kays, 1991).

In developing countries sweetpotato is grown on small or large scale. In some regions the peasants grow this crop in small plots, mixed with other crops using the intercropping system, for consumption or to be marketed (FAO, 1988). For industrial use, this crop is grown on large scale farms. Sweetpotato is an important staple food in many countries but it also has significant meanings in cultural and social occasions. For example, in the United States sweetpotato is part of the Thanksgiving meal, in Nepal it is a sacred food, and in Japan it is processed into luxury items for gifts (Woolfe, 1992).

WORLD PRODUCTION OF SWEETPOTATO

The world production of sweetpotato was about 124 x 10^6 metric tons in 1994 (Table 1). China contributed 85% of the world production, followed by Vietnam, Uganda, Indonesia, Japan, India, and Rwanda. The 1994 production was 7% less than that in 1979-81. However, Africa had an increase of 29%. The United States produced 0.6 x 10^6 metric tons in 1994 which represents an increase of 6% compared to the production of 1979-81 (FAO, 1994). Among the States, Louisiana is the second largest producer following North Carolina, with a total production of 0.164 x 10^6 metric tons in 1995 (Picha and Hinson, 1996; USDA, 1996). Sweetpotato is one of the top ten food crops produced in the world after wheat, rice, maize, potato and barley (Bradbury and Holloway, 1988; Bouwkamp, 1985).

Table 1. World production of sweetpotato roots.

Producer	Area (1000 ha)		Production (1000MT)	
	24.43209877	1994	1979/81	1994
World	**10870**	**9380**	**134232**	**124339**
Asia	9382	7587	125506	114341
China	*7962*	*6511*	*114257*	*105180*
Africa	1009	1384	5379	6944
N C America	196	166	1313	1140
USA	*44*	*33*	*561*	*593*
S America	165	116	1394	1248
Oceania	106	121	510	600
Europe	12	5	130	60

(Source: FAO Yearbook 1994, vol. 48)

NUTRITIONAL VALUE OF SWEETPOTATO STORAGE ROOTS

The sweetpotato is a rich source of calories. Its content of dietary fiber, beta-carotene, vitamin C and other specific nutritional factors make this crop more popular, particularly in developed countries. Although the world consumption of sweetpotato declined in the last decade, its market may increase again. In developing countries the sweetpotato is a subsistence food. In developed countries, particularly in the United States, the interest in sweetpotato increased after being considered a convenient food, with nutritional advantages due to its content of beta-carotene and dietary fiber. Frozen products have been developed to increase the demand in the American market (Tsou and Hong, 1992; Walter and Wilson, 1992).

The chemical composition of sweetpotato roots depends on cultivar and environmental conditions. The major components of sweetpotato roots are starch (44-78%); sugar (8-27%); protein (1-12%); fiber (2-8%) on a dry weight basis. Dry matter accounts for 12-42% of root weight. It is highly nutritive not only due to the starch content that gives calories but also due to its content in protein, vitamins and minerals (Tsou and Hong, 1992). This crop was compared with some crops regarding the number of people to whom one hectare can give nutrients daily. It was reported that one hectare of sweetpotato gives sufficient energy for 20-92 people depending on the yield, while cassava serves 13, beans six, rice 14, and maize 13 people. In terms of vitamin A, vitamin C, and iron, one hectare of sweetpotato gives about the same or more than other crops (Woolfe, 1992). The most abundant vitamins are provitamin A and vitamin C (20 mg/ 100gr). Vitamin A in orange cultivars represents 72% of the total nutritional value (7100 IU/100g). Vitamin C is present

at levels of 20-50 % fresh weight. Other vitamins present in fair amounts are thiamin (0.08 mg), riboflavin (0.05 mg), and niacin (0.9 mg). Proteins in sweetpotato are distributed throughout the root and its nutritional quality is high. Dietary fibers include cellulose, hemicellulose, and pectins. In baked roots these dietary fibers represent about 1, 3, and 0.3%, respectively. Lipids and minerals are not significant in sweetpotato roots. Besides nutritional components, sweetpotato roots have small amounts of antinutritional factors such as trypsin inhibitors, phytates, tannins, and oxalates (Winarno, 1992; Oboh *et al.*, 1989; Collins and Walter, 1985). Chemical analysis of cell walls from sweetpotato starch residue demonstrated that it contains pectins, cellulose, hemicelluloses. Glucose was among sugars present in the cell wall fractions (Noda *et al.*, 1994).

CONSUMPTION OF SWEETPOTATO AND ITS PRODUCTS

Sweetpotato is a staple food, home prepared fresh in many countries of Africa, Asia and South America. In developed countries, this crop is largely processed by industry. The use of sweetpotato roots is increasing both in developing and developed countries due to its growing flexibility and nutritional quality. It supplies nutrients with healthy properties, and it may be used to combat hunger and malnutrition. Sweetpotato is included in the list of food items defined by NASA for space missions. It was also part of diets for special studies like Biosphere 2. It has been studied in specific environments such as hydroponic systems, by EPCOT Center-Orlando and by Tuskagee Research Center.

The storage roots of sweetpotato are consumed in several ways: baked, steamed, fried, pureed, and mixed with other food items. According to the region and type of dishes, the preference varies in terms of root texture, starch and water content, and flesh color.

Besides the fresh roots for baking, the most common sweetpotato items in the United States are the frozen products (Walter and Wilson, 1992; Wu *et al.*, 1991), patties (Walter and Hoover, 1984; Hoover *et al.*, 1983), dehydrated cubes and flakes (Walter and Purcell, 1976; Hoover, 1967; Hoover and Kushamn, 1966, Spadaro *et al*, 1967), chips and french-fried products (Schwartz *et al.*, 1987; Walter and Hoover, 1986; Hoover and Miller, 1973; Arthur and McLemore, 1955), canned sweetpotato (Ice *et al.*, 1980), and flour or puree (Silva *et al.*, 1989) used for baby food, pie filling, and pasta. Other products are candies, cookies, sauces, beverages, yogurt, snacks, starch sweetening agents, and as supplement of vitamin A. Besides roots, the young leaves are also consumed in gravies and sauces and as a green vegetable. They are a rich source of proteins and vitamins (Kordylas, 1990).

The main constraint in sweetpotato acceptance by consumers is its strong flavor from volatile compounds. Sweetness is also a dominant taste of U.S. cultivars, especially in cooked roots, due to maltose production. Root color also influences the consumer's acceptance depending on the region and type of sweetpotato product. Texture is important for the mouthfeel property of a product. Sweetpotato can be used for other industrial purposes such as production of starch, alcohol, chemicals, and for animal feed. (Winarno, 1992; Hill *et al.*, 1992; Thirumaran and Ravindram, 1992; Johnson *et al.*, 1992; McLaurin and Kays, 1992; Collins and Walter, 1985; Anonymous, 1976).

SWEETPOTATO STORAGE ROOT MORPHOLOGY

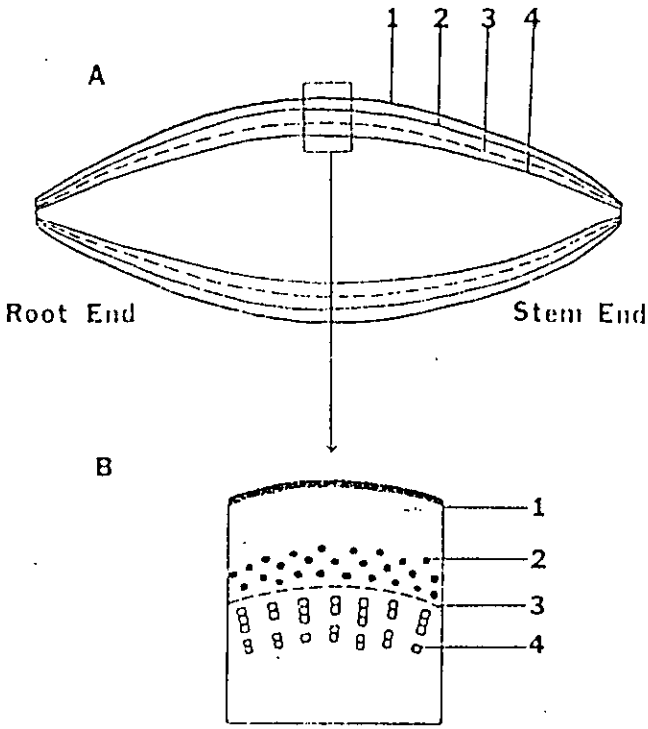
The sweetpotato storage roots are formed from young thick adventitious roots. Description of storage roots is usually based on root shape and thickness; skin or peel texture and color; and flesh color and texture (CIP/AVRDC/IDPGR, 1991; Groth, 1911).

They are composed of different cell types arranged in layers or clusters. Roots can be divided into zones according to cell type. Walter and Schadel (1982) classified the following zones in sweetpotato roots (Figure 1): (1) periderm or the outermost tissue, also called peel, skin, cork, or bark; (2) cambium, the outer tissue or ring of the vascular cambium just under the periderm that includes the lacticifer cells exterior to the cambium and the cambium; and (3) innermost tissue or core that includes the xylem elements interior to the cambium, the storage parenchyma, and the anomalous cambia up to the center of the root. Zones in orange flesh roots have distinct colors. The cambium ring is light orange and the inner tissue is dark orange. Differences of color can be seen with the unaided eye, and help separate the zones (Hagenimana *et al.*, 1994; Noda *et al.*, 1992; Edmond and Ammerman, 1971).

Zones have different proportions and properties. In two Japanese cultivars, the inner tissue (IT) was greater than 50% of root weight, peel (P) was about 10%, and cambium © represented about 15%. The three zones had different proportions of starch content being higher in the inner tissue, followed by cambium and peel. Starch from the cambium was more susceptible to enzymatic activity, probably because the cells are young and late-formed. Similar results were found in rice (Noda *et al.*, 1992; Fujimoto *et al.*, 1971).

INFLUENCE OF STORAGE ROOT SIZE UPON CHARACTERISTICS OF RAW AND COOKED SWEETPOTATOES

Sweetpotato root size may be defined by its diameter and/or length. It is the parameter used in root selection for harvesting. Sweetpotato roots do not have other specific signs to indicate its maturity. Size may be related with root age, with young roots



(Source: Walter Jr. and Schadel, 1982)

Figure 1. Sweetpotato root longitudinal (A) and transverse (B) sections with relative locations of tissues and cell types: 1- periderm; 2- lacticifer; 3- cambium, 4- xylem element.

being smaller than old roots. However, the normal growth of roots may be affected by adverse conditions such as heavy soils, drought, pests, diseases, or lack of space, all of which may block the enlargement of the roots.

Root grading is based on standardized sizes for commercial purposes. The standard sweetpotato grades defined by USDA are: U.S. Extra No. 1. for roots 3"-9" long and 1 3/4"-3 1/4" diameter having a maximum weight not more than 18 ounces; U.S. No. 1 for roots 3" -9" long, 1 3/4"- 3 ½" diameter, maximum weight not more than 20 ounces; U.S. Commercial for roots with U.S. No. 1 grade but with an increased tolerance for defects is allowed; U.S. No. 2 for roots with minimum size not less than 1 ½" and maximum weight not more than 36 ounces (Boudreaux, 1996). The old classification was in four groups: 'Number one' for roots from same cultivar, without defects, with 1.75"- 3.5" diameter and 4"-10" length; 'Number two' for roots from same cultivar, without defects, with 1.5"-3.5" diameter; 'Jumbo' for salable roots with more than 3.5" diameter and, 'Number three' for salable roots without previous specifications. Grading is important for industry because different size roots have different characteristics. For instance large roots require longer cooking time and roots with diseases or injuries require longer time for peeling (Woodroof and Atkinson, 1944). The canning industry prefers small roots and the fresh market industry has a preference for medium size. Jumbo or large size and misshaped roots are not in demand (Hoover *et al.*, 1983) but may be utilized by the canning industry for 'cuts', mash packs, and production of purees.

Studies on roots size and age reveal an influence on changes in physicochemical composition of roots. In Japanese cultivars, roots harvested earlier were smaller than late

harvested roots. Older or larger roots had lower pasting temperatures, higher viscosity, low ratio short/long chains of amylopectin, and low starch breakdown. The shape of starch granules did not differ either by zone or by age (Noda *et al.*, 1995; Takeda *et al.*, 1986).

Large roots lost weight slower than small roots during cooking. They also needed more time for cooking (about 10 minutes) to have the same texture as the small roots. Firmness of cooked roots was influenced by size or age. Young roots had higher degree of firmness than old roots (Scott and Bouwkamp, 1975; Hoover and Stout, 1956). Rate of heat penetration into the root depended on cultivar and size. Mandava (1995) reported a higher rate in 'Beauregard' than in 'Jewel'. In small roots the heat penetration was faster than in medium and large roots. A temperature of 98 °C at the center of the roots was reached at different rates; after 30 minutes in 'Jewel' and after 26 minutes in 'Beauregard'. Similar results were observed in other cultivars (Woodroof and Atkinson 1944). Wadsworth and Spadaro (1970, 1969) investigated heating penetration in 'Goldrush' roots and by computer simulation. They observed that the heat penetration and diffusivity were influenced by root size. For a certain heating time, the heat penetration was higher in small roots and might reach the center of the roots but in large roots the same temperature was found in lower depth. Mandava (1995) observed that changes in small and large roots depended on cultivar and cooking time. Starch was not significantly different in raw roots of small, medium and large sizes of 'Beauregard' and 'Jewel' roots. When cooked, small roots had more starch than large roots in both cultivars. Maltose content increased more rapidly in small than in large roots during heating.

In 'Porto Rico' sucrose in raw small roots was (3-4 % fresh weight), less than in large roots (4.2 %) but more than in medium roots (1.8 %). Cooked small roots had less sucrose (3-4 %) than large (5-6 %) and medium roots (0.5-1.0 %). Glucose concentration was not changed by processing but by size. It was about 1.4 % in large, 1.2 % in medium, and 0.9 % in small roots, raw or cooked. Maltose was affected by both size and processing. It was 3-10% in cooked large roots and 9-11% in medium and small roots. Size influenced the rate of heat penetration and consequently the starch conversion into sugars. The rate was lower in large roots (Woodroof and Atkinson, 1944).

Peel thickness and peeling losses are influenced by root size. Small roots have thinner peel than large roots when they are freshly harvested. In cured roots both sizes have similar thickness. During curing the skin becomes thicker, harder and resistant to external factors. Peeling losses were higher in small (34%) than in large roots (15%) of cured 'Porto Rico'(Woodroof *et al.*, 1955).

EFFECTS OF CURING AND STORAGE ON SWEETPOTATO ROOTS

General Requirements and Root Changes

Curing is a post-harvest treatment before storage that consists of holding the roots for four to seven days at 29-32°C and 80-95% relative humidity. It is recommended that roots be placed in a curing room preferably within two hours after harvest. Curing hardens the skin, heals cuts and bruises with the formation of periderm, and it contributes to a better appearance of roots. Curing reduced loss of water and the microbial and insect activity in injured roots (Boudreaux, 1996; Winarno, 1992; Kordylas, 1990; Edmond and Ammerman, 1971).

Curing and storage extend the shelf-life of harvested roots, maintaining them as fresh as possible until they are consumed. It is recommended that cured roots be stored at 13-16°C and 85-95% relative humidity. Storage alters the metabolic activity of roots such as respiration and transpiration which may influence root appearance. According to Picha (1986c), the weight loss in 'Jewel' was lower than in four other cultivars and higher than 'Rojo Blanco'. Transpiration, considered the major cause of weight loss of stored roots, was high during curing but was reduced during storage. Respiration was high at harvest and was reduced during curing and storage. It was not directly related to weight losses but respiration influenced weight loss during the last period of storage. For example, weight loss in 'Jewel' was 28mg/g fresh weight after curing and 69mg/g after 50 weeks storage for a total loss of 97 mg/g. The appearance of stored roots did not change which suggests that 'Jewel' is a suitable cultivar for long storage.

Effects of Curing and Storage on Roots Carbohydrates

During curing and storage starch is converted into sugars. Various studies have been done on the influence of environmental conditions on starch conversion, alcohol insoluble solids (AIS) reduction, alpha-amylase activity and sugar production. Raw and various cooked products from different cultivars were used for analysis. The results show a similar trend for each component. The reduction of AIS and the increase of individual or total sugars depended on curing, storage temperature and duration, and type of sweetpotato product. Wilson *et al* (1994) studied 'Beauregard' and 'Jewel' roots cured and stored up to eight weeks at 1.5°C and 15°C. Raw roots were steamed at 100°C for different durations. They observed that the sugars content was higher in 1.5°C than in 15°C storage

during the same period of time. Comparing cultivars, 'Jewel' had more sucrose, less glucose, and about the same amount of fructose than 'Beauregard' at 1.5°C storage. When the storage temperature was 15°C glucose and fructose were lower in 'Jewel' and sucrose was higher than in 'Beauregard'.

Picha (1986d, 1987) presented results of six cultivars whose roots were cured for 10 days at 32°C and 90% relative humidity (RH) and stored for 46 weeks at 90% RH and at two different temperatures, 7°C and 15.6°C Sucrose increased from 1.98% fresh weight after harvest to 3.22% after curing. Cured roots had twice as much sucrose after four weeks storage being 6.45% at 7°C and 3.09% at 15.6°C. Sucrose content of orange-flesh cultivars increased with storage, probably due to starch degradation by phosphorylase. Glucose increased from 0.12% at harvest to 0.70% after curing. After four weeks storage at 7°C glucose content did not change, it was 0.70%, but at 15.6°C it increased to 1.08%. Fructose increased in 'Jewel' roots from 0.11% at harvest to 0.44% after curing, to 0.57% after four weeks storage at 7°C and to 0.66% at 15.6°C. Total sugars increased in cured and stored Jewel roots at 7°C, from 2.21% at harvest to 4.36% after curing, to 7.72% after four weeks storage at 7°C and to 4.83% at 15.6°C. The increase of total sugars after storage at 7°C was due to sucrose produced under same conditions. Other characteristics of roots also influenced sugar production. For example, in cured and stored roots at 7°C sucrose increased in orange-flesh cultivars ('Centennial', 'Jewel', 'Jasper', and 'Travis') and decreased in white-flesh cultivars ('Whitestar' and 'Rojo Blanco'). When stored at 15.6°C sucrose content increased in all cultivars.

In a previous study, Picha (1986b) demonstrated in baked 'Jewel' that sucrose, glucose and fructose increased with curing and storage. At harvest and after 14 weeks storage sucrose content was 2.63% and 4.18% (fresh weight), respectively. Similarly, glucose was 0.15% and 1.19%, and fructose was 0.11% and 1.3%, respectively at harvest and after 14 weeks storage. Total sugars increased from 12.59% at harvest to 14.22% after 14 weeks. Maltose was the sugar in highest concentration in baked roots followed by sucrose, in amounts that depended on storage length. Maltose in baked roots was 9.70% at harvest, 7.06% after curing and 7.55% after 14 weeks of storage. In baked roots AIS content decreased from 22.5% (fresh weight basis of raw roots) at harvest to 17.8% after curing and to 16.1% after 14 weeks. Picha (1986a) compared sugar content in cured/ stored roots from six cultivars before being processed into chips. Sugar content of 'Jewel' roots after curing and storage for 12 weeks at 15.6°C was (in fresh weight basis of raw roots) 1.22% glucose, 1.01% fructose, 2.78% sucrose, representing an increase of sugars compared with freshly harvested roots. Changing storage temperature did not reduce glucose and fructose. Sucrose was the sugar in higher concentration in raw roots. Glucose and fructose followed sucrose with some variation depending on the cultivar. In 'Jewel' both sugars were about the same amount. In cooked roots, maltose was the sugar in greatest concentration, sucrose the second, followed by glucose and fructose.

In 1985, Picha reported on sugar concentration in cured 'Jewel' roots stored for 3 months at 15.6°C. Sucrose changed from 2.78% in raw to 3.98% (fresh weight basis) in baked roots, glucose from 1.22% in raw to 1.29% in baked roots, fructose from 1.01 in raw to 1.20% in baked roots. Walter and Hoover (1984) also observed in sweetpotato patties

made from 'Jewel' that starch decreased and sugar increased with storage and processing. Starch content at harvest was 15% (fresh weight) in raw roots and 9% in cooked roots. It reduced to 10% and 9% in raw roots and to 6% and 7% in cooked roots stored for three and four months, respectively. Sucrose increased from four to 5% in cooked and raw roots; glucose and fructose did not change much during this period, being about 2.5 %. Maltose was not detected in raw roots, and in cooked roots it decreased from about 3.5 to 2.5 % in three and four months stored roots, respectively.

Walter *et al.* (1975) found that sugar content increased with storage in raw and baked sweet potatoes at different rates; in raw roots the sugar content increased from about 2% (fresh weight) at harvest to 6% after 71 days storage. In baked 'Jewel' and some other cultivars the starch conversion into maltose was 63-69% at harvest and 91-95% after 71 day storage. Hamann *et al.*(1980) compared the quality of baked roots from uncured and cured 'Jewel' roots freshly harvested. They verified that baked cured roots were more viscous, sweet and moist, and less chalky than the uncured roots. Walter and Palma(1996) studied the effect of long-term storage on cell wall composition of 'Jewel' and 'Beauregard'. They reported that glucose was the sugar in higher concentration in the cell wall. The storage did not change the neutral sugars. Storage reduced the water-insoluble and increased the water-soluble pectic substances causing the root softness. Other studies analyzed other cultivars with results showing the same trend in AIS reduction and sugar increase during curing and storage (Reddy and Sistrunk, 1980; Sistrunk, 1977; Hammet and Barrentine, 1961; Jenkins and Gieger, 1957a, b, c).

Storage influences the quality of processed products and consumer's acceptability. Madamba *et al.*(1977) reported that storage did not affect baked products. Consumers acceptability was reduced in boiled or fried products made from stored roots of Philippino cultivars. Storage at 10°C increased starch conversion and sugar production changing the product quality. Schwartz *et al.* (1987) reported that storage did not cause major changes in the composition and quality of frozen sweetpotato french-fried products, only vitamin C was reduced by 58%.

EFFECTS OF PEELING ON STORAGE ROOTS

Peeling is the procedure of removing the skin, cortex and corky layer of the root (Woodroof *et al.*, 1955). There are several methods of peeling such as using steam boiling water, salt solution, baking, lye solution and by hand.

Lye-peeling is often used for peeling of whole sweetpotato roots prior to canning. It consists in submerging the roots in a 10% NaOH solution at 104°C for about 5-6 minutes and washing the roots in a water spray. Starch hydrolysis of the outer layer (5-8mm deep) of the roots occurs during this operation. Walter *et al.* (1976) observed in raw puree from lye-peeled roots of 'Jewel' the immediate starch conversion and maltose production and changes in amyloid components of subsequent sweetpotato flakes. After three days storage, roots were washed, lye-peeled and pureed. The results from quick steam injection at 103°C were compared to cooking at 75°C for 10 to 120 minutes with steam injected at 103°C to stop enzyme action. Flakes prepared from puree processed with steam injection had 12.5% maltose on a dry basis. The amount of maltose produced during peeling was not expected and led to another study on effect of peeling method on sugar production. It was known

that gelatinization of sweepotato starch occurs at 68-73°C and both α- and β-amylases act only on gelatinized starch. Lye-peeling was compared with hand-peeling. Maltose production was 0.1% in non-heated hand-peeled roots, 0.6% in steam injected roots, and 15.6% in lye-peeled roots. Dextrins slightly increased from 7.7% to 8.5% during the 120 minutes processing. The inner tissue of lye-peeled roots did not change, where the heat did not penetrate, comparable to hand-peeling. The enzymes located in the inner tissue might react with the gelatinized starch of the outer layers of the lye-peeled roots when the puree was prepared (Ikemiya and Deobald, 1966). Walter and Giesbrecht (1982) also studied sugar production in lye-peeled 'Jewel'. There was always an increase of sugar concentration, mainly in the beginning of the process, in amounts that depend on the duration of lye-peeling, while enzymes were active to breakdown the starch.

Lye-peeling causes root discoloration in raw sweetpotatoes, affecting their appearance. This is one of the major concerns of processors. It is the result of enzymatic reaction of polyphenoloxidase with o- dihydroxy phenols. The temperature used for lye-peeling disrupts the lacticifer cells but does not inactivate the enzyme located there. The enzyme reacts with the phenols located in the lacticifers and in the parenchyma storage cells (Walter and Schadel, 1982). This discoloration problem is a concern in processed products, particularly in frozen and dehydrated sweetpotato flakes (Hoover and Miller, 1973; Hoover, 1963). The intensity of discoloration depends on root quality, length of storage, and type of cooking. For instance, roots stored at low temperatures had good color. Longer storage caused more discoloration. Bruised and boiled roots had more discoloration than the non-

bruised and baked roots. Color and firmness improved when the pH was reduced and were retained when the roots were treated with buffer solution before processing (Sistrunk, 1977, 1971).

EFFECTS OF COOKING ON SWEETPOTATO ROOTS

The first report on changes in composition of sweetpotato during cooking was from W.E. Stone in 1890, concluding that dextrins formed during cooking. In 1920-22 other studies with 'Porto Rico' cultivar reported that sweetpotato was rich in diastases. Starch changed into dextrin and maltose when roots were slowly cooked or in canned roots. His study carried out in 1923 with 'Southern Queen from Arlington' and 'Nancy Hall' cultivars, demonstrated how cooking caused starch saccharification into sugars, considered as maltose. The starch conversion was due to the diastatic enzymes, and did not occur at boiling temperatures but readily occurred in the first minutes like in cereals. Because sweetpotato roots have a high concentration of starch convertible into sugars, Gore questioned if sweetpotato could be called a saccharine instead of a starchy food (Gore, 1923).

Purcell and Walter (1988) reported that carbohydrates in 'Jewel' roots baked in a microwave for 3 minutes were different than the sample baked in conventional oven for 90 minutes at 190°C. The content in reducing sugars, dextrins, and starch were not directly correlated with the storage time, probably because the process does not give time enough for the starch degradation by enzymes. Roots stored for 63 days and baked in oven had 6% starch, dry-weight basis, and in the microwave it was 37% starch. Total soluble sugars were 34% and 55% in the microwave and convection oven, respectively and the reducing sugars

were 6% and 23%, respectively. Walter *et al.*(1976) studied changes in 'Jewel' roots during preparation of sweetpotato flakes by enzyme activation technique. The physicochemical changes of roots occurred in the first 10 minutes. Starch highly decreased in the first 60 minutes. Lye peeling caused starch gelatinization in the cambium. During puree making the enzymes located in the inner tissue acted on gelatinized starch with the consequent production of dextrins and sugars. McArdle and Bouwkamp (1986) reported that heating time in an open kettle did not affect sugars but the heating temperature caused changes. When the temperature increased from 50°C to 70°C in puree made from 'Rojo Blanco', maltose increased. Above 70°C, it decreased. With AIS, it was the reverse. They concluded that 80°C was the temperature for maximum starch conversion, but it depended upon sweetpotato cultivar.

Blanching is another step that is used in sweetpotato processing. It influences the chemical composition of the product. Walter and Hoover (1986) reported in their study on french-fried sweetpotato products that blanching affected starch conversion. Blanching increased temperature to above the gelatinized temperature inside the roots, causing enzymatic hydrolyses. Blanched samples had less reducing sugars and sucrose than the raw samples because of the use of water as the heating medium.

AMYLASES IN SWEETPOTATO

Sweetpotato (storage) roots contain several enzymes that control the metabolic processes for the plant adjustments to the environmental changes. Kays (1992) listed about 58 enzymes in the sweetpotato roots. The amylases, α- and β- amylases (initially called diastases) are the most important enzymes in sweetpotato processing and their effect is

related to the diastatic power of the substrate (Briggs, 1961). These hydrolyzing enzymes are involved in seed germination and they are responsible for the starch conversion into maltose and other soluble carbohydrates (Hagenimana *et al.*, 1994; Woolfe, 1992). Starch conversion changes the rheologic and organoleptic properties of the final product such as color, texture, viscosity, mouthfeel and sweetness (Woolfe, 1992; Hoover, 1967). These characteristics are a major concern in sweetpotato canning and flake production, in achieving the product quality and consumer acceptability. Starch content in sweetpotato is high and the endogenous amylases cause starch breakdown into soluble carbohydrates during curing, storage, and processing. Enzyme activity influences the textural characteristics and sugar content of cooked roots. Alpha- and beta- amylase are also involved in carbohydrate migration along the plant but they become very active at gelatinization temperature.

Characteristics of Amylases

Alpha- amylases (1,4-α-D-glucan-4- glucanohydrolase) (E.C. 3.4.1.1) are the main starch degrading enzymes. They exist in animals (saliva and pancreas), plants, and microorganisms (fungi and bacteria). Alpha-amylase is also called dextrinizing amylase or liquefying enzyme. They hydrolyze randomly the internal α- D-(1,4)-glucosidic linkages in the amylopectin or other polysaccharides with 3 or more 1,4- α-linked D-glucose units (amylose, glycogen, and dextrins) with consequent reduction of molecular weight of the substrate. This activity changes the iodine-staining properties (dextrinizing activity) and reduces product viscosity due to cleavage of glycosidic bonds. The reduction ability or saccharifying activity of the solution increases. Alpha- amylase, as an endoenzyme, attacks

the interior bonds of starch chains. The end products from the reaction of α-amylase on amylopectin are maltose, limit dextrins and D-glucose. Maltose cannot be hydrolyzed by this enzyme. The limit dextrins are starch fragments with α-D-1,6 linkages, not hydrolyzed by α- amylase. This enzyme cannot hydrolyze α-D-1,3 linkages, α-1,4-glucosidic bonds within two residues of an α-1,6- bond in an amylopectin chain or α-1,6- glucosidic bonds in the branching points of the chains.

Beta-amylase, β-1,4-D-glucan maltohydrase (EC3.2.1.2), is an exoenzyme, also called saccharogenic amylase, maltohydrolase, maltohydrase, or sugar-producing enzyme. It hydrolyses α-1,4- D-glycosidic linkages only in the penultimate bond from the nonreducing end group of the starch chain in the 1,6 bond of the amylopectin chain in β-anomeric form. Beta-amylase produces limit dextrins and maltose from amylopectin (Howling, 1989; MacGregor, 1988; Lee, 1983; Briggs, 1961; Nakayama and Kono, 1957). Alpha- amylase may attack native starch granules while β-amylase acts only in gelatinized starch. While all of the amylose molecule is cleaved into maltose, only 60 % maltose is produced from amylopectin with 40% remaining as dextrins.

Alpha- amylase is heat labile in some plants (alfalfa and soybeans),and stable in barley malt and sweetpotatoes. Its activity ranges from 0.009 U/g fresh weight in tomato fruit and carrot root to 0.130 U/g in sweetpotato root and 0.726 U/g in bush bean pod. Bush beans and potatoes are considered rich sources of α-amylase activity while alfalfa, soybean, and sweetpotato roots are considered rich sources of β-amylase activity. Alpha-amylase not only varies from species to species but also depends on the plant parts. It is present in low concentrations in the endosperm of cereal seeds where the starch is

concentrated (Hagenimana *et al.*,1994; Doehlert and Duke, 1983). Enzyme activity has been also studied in order to reduce the energy costs for cooking process to starch gelatinization and saccharification (Noda *et al.*, 1992). At the genetic level, it may give better identification and specificity to enzymes especially enzymes that share the same domain, such as those acting on amylose, amylopectin and related oligosaccharides.

The chemical structures of α-amylases show that they are multidomain proteins, with more than one folding. Different end-products produced by different sources of α-amylase may be due to differences in the enzyme active sites, in number of subsites, and affinity of each subsite for a glucose residue (MacGregor, 1993).

Sweetpotato α- amylase was characterized as having high optimum activity temperature (70-75°C), heat stability, present in low amounts in freshly harvested roots, but increasing with storage. It is concentrated in the inner tissue and is more soluble in water than in sweetpotato juice (Hagenimana *et al.*, 1992 a,b; Ikemiya and Deobald, 1966). The increase of α- amylase during storage enhances the quality of sweetpotato flakes. It has been considered that firmness of canned roots is due to low α-amylase of freshly harvested roots. Processing quality of sweetpotato flakes also depends on enzyme activity (Ikemiya and Deobald, 1966). It may also depend on the amount of starch that was not hydrolyzed, the amount and size of the dextrins, and the amount of sugar present (Walter *et al.*, 1975). The enzyme activity and quality of sweetpotato flakes depend on various factors such as type of cultivar, harvest season, root freshness, enzyme concentration, and reaction conditions, mainly temperature, pH and salts. The optimum temperature for α-amylase activity is above

the temperature of gelatinization and depends on the cultivar (Takeda *et al.*, 1986; Hoover, 1967; Spadaro *et al*, 1967).

The enzyme changes the content of different sugars either in storage or during root processing. Levels of sugars produced depend on the concentration of α- and β-amylases and the amount of gelatinized starch to be converted into sugars. During lye peeling, starch from the outer zone of the root is gelatinized and the degree of gelatinization depends on the size of the roots. Preheating of roots decreases enzyme activity and consequently maltose production. Control of amylases is critical to maltose production which is the major sugar that affects the quality of sweetpotato flakes. This sugar is formed in excess when the enzyme concentration is very high, in cured roots. In fresh roots, the enzyme activity may be reduced by increasing the temperature of processing and reducing the conversion time, resulting in less maltose. In ground material after curing, at 75- 95°C, and at 100°C, the enzyme activity was 5.30- 5.34, and 4.47 SDU, respectively (Deobald *et al.*, 1969). Enzyme treatment significantly reduces puree viscosity, being thinner with cured and stored roots than with the uncured and stored roots (Ice *et al.*, 1980).

Two methods were defined for using the native enzymes - the add-back system of the treated material after using a commercial enzyme for starchy and uncured roots, and the enzyme-activation technique. The add-back method is the enzyme process used for flake production from uncured and starchy sweetpotato roots. It consists of treating a portion of sweetpotato puree with about 0.05% of an amylolytic enzyme, waiting 1 hour or more, until most of starch conversion occurs. The enzyme treated puree or add-back is heated to inactivate the enzyme. This treated portion can be mixed with untreated material (Hoover,

1966). The enzyme-activation technique is used for flake production from cured, starchy, and freshly harvested roots. It is based on preheating the roots by steam injection at 89-103°C for 60 minutes to activate the saccharifying enzyme system. The material is kept for conversion in a tank for up to 1 hour. Afterwards, it is heated again at higher temperature of about 111°C to inactivate the enzyme and complete the cook (Hoover, 1967; Hoover and Harmon ,1967).

Commercial α-amylase can be purified from animal pancreas and saliva, cereals, and microorganisms (fungi and bacteria) (MacGregor, 1988; Thoma, 1976; Bernfeld, 1955). Valetudie *et al.* (1993) studied the hydrolysis of tropical tuber starches by bacterial and pancreatic α-amylases. The starch hydrolysis is higher with *Bacillus subtilis* amylase (11.7%) compared to porcine pancreatic enzyme (8.1%). It was also reported that increasing the hydrolysis time from 6 hours to 24 hours, the hydrolysis becomes higher with pancreatic (33%) than with bacterial α-amylase (25%). The hydrolysis rate depended on type and susceptibility of the starch granules to the reaction with the enzyme from both sources. This study also confirmed that the enzymatic hydrolysis in non-cereal starches is lower than in cereal starches. There were differences due to the enzyme source in the characteristics of starch granules after hydrolysis such as size, shape and smoothness of the surface. The bacterial enzyme disintegrated the starch granules while with the porcine pancreatic enzyme the outer layer of the granules remained. The enzymes appeared to have hydrolyzed first the internal part of the granules, then the external layers.

These findings contradict the results of Seneviratne and Biliaderis (1991). In a study on the action of α-amylases upon amylose-lipid complex superstructures, these authors used

wheat starch, *Bacillus subtilis* and hog pancreatic α-amylases. The animal enzyme had higher degradation rate than the bacterial enzyme.

Chang Rupp and Schwartz (1988a, 1988b) studied the characterization of the action of *Bacillus subtilis* α-amylase on sweetpotato starch, amylose and amylopectin, of 'Jewel' cultivar. They reported that the hydrolysis of starch is a nonrandom process. The hydrolysis of amylose formed high molecular fragments which were hydrolyzed into oligosaccharides. The amylopectin was hydrolyzed into polysaccharides by α-amylase. They observed that the heat of lye-peeling caused starch gelatinization and enzymatic reaction. The native enzymes were inactivated when the roots were treated by steam injection at 103°C for 5 minutes. The molecular weight of carbohydrate products depended on the enzyme used for treatment (endogenous or exogenous) and the conversion period (beginning or end of the process). Molecular weight was lower when commercial *Bacillus subtilis* α-amylase was used at the end of the process. Amylases can be considered as having liquefying, saccharifying or dextrinizing power depending on the method used to determine the enzyme activity (Fuwa, 1954).

Methods of Analysis of Sweetpotato Alpha- amylase

Different methods have been applied to determine α- amylase activity using various sources of substrate. They are, in general, based on the following phenomena: (1) increase in reducing power of a solution of amylopectin or soluble starch, (2) change of the iodine-staining properties of the substrate, or (3) decrease of the viscosity of a starch paste (Bernfeld, 1955). Adding to these phenomena, Fuwa (1954) considered two more properties, namely changes in optical rotatory power and decrease in the turbidity of

glycogen solution. All of these properties are applicable to α-amylase but only the first characteristic can be considered for β-amylase. The analytical methods can be viscosimetric, saccharogenic, turbidimetric, nephelometric, amyloclastic, colorimetric or chromogenic, individually or combined, and lately by immunological detection. The first three methods require a stable and reproducible starch solutions and special equipment (Kaufman and Tietz, 1980).

The analytical methods have been used in different products besides sweetpotato, such as in wheat flour and barley malt (Perten, 1984); in potato or corn starch (Rinderknecht *et al.*, 1967); in human salivary (Bernfeld, 1955); and in germinated barley (Schwimmer and Balls, 1949). The results are expressed in different units and defined by different procedure such as (a) sweetpotato dextrinizing units (SDU), (b) absorbance, (c) α- amylase units (APA), (d) percentage, (e) per gram of fresh sample or (f) per ml of crude juice. The amyloclastic and chromogenic methods are the most common for enzyme determination in sweetpotato. The amyloclastic method is based on the rate of enzymatic hydrolysis of a soluble starch substrate, in which the blue color from added iodine decreases with the increase of enzyme activity on the substrate. Sandstedt, Kneen, and Blish modified the Wohlgemuth method used for determination of total enzyme (α- and β- amylase) activity in order to be selective for α-amylase. The modification was the addition of sufficient β-amylase to eliminate the effect of this enzyme already present in the malt extract (Hasling *et al.*, 1973; Ikemiya and Deobald, 1966; Briggs, 1961; Sandstedt *et al.*, 1939).

The analysis of α-amylase activity may take into account the interference of β-amylase also present in the same tissue, which may be inactivated by heating the sample

(Schwimmer and Balls, 1949). The chromogenic method is based on hydrolysis of substrates that are insoluble derivatives of starch, giving a color for which the intensity increases with an increase in enzyme activity. A chromogenic method was created specifically for sweetpotato by Walter and Purcell (1973), based on the AOAC (1960), in which the α-amylase activity is expressed in APA units per ml of juice using the formula: APA amylase units/ ml= [(Abs_{595}- Abs_{595} (blank)): Abs_{595} of 0.1 M Cu SO_4] x Dilution factor. Other chromogenic method, more appropriate for clinical purposes, is the starch substrate labeled covalently with Remazolbrilliant Blue (RBB), developed by Rinderknecht *et al.*, 1967.

Influence of Temperature on Alpha- amylase Activity

Several studies have been done and some methods were developed to study the action and optimal conditions of α- amylase. This enzyme is stable at 75°C. At this temperature β-amylase was inactivated. The end products of starch conversion are measured by the amount of simple sugars (glucose and fructose), reducing and nonreducing disaccharides (maltose and sucrose, respectively), and total sugars produced depending on the temperature of conversion and on the cultivar. In 'Goldrush' the optimum enzyme activity for good quality flakes was between 0.31 SDU and 0.51 SDU in fresh roots and about 0.22 SDU in preheated roots. The preheating step reduced the enzyme activity depending on the time and temperature of the reaction (Ikemiya and Deobald, 1966). The enzymes located in the inner zone might combine and react with the gelatinized starch of the outer layers of the lye peeled roots as puree was prepared. The inner tissue of lye-peeled roots did not change. The area where the heat did not penetrate can be compared to hand-peeled roots. This might be due to the location of hydrolyzing enzymes in the outer layers

of the root that are removed in hand-peeling (Chan-Rupp and Schwartz, 1988a; Walter *et al.*, 1976).

Liu (1995) observed that α-amylase was influenced by length of storage depending on the processing temperature. In four cultivars, including 'Beauregard' and 'Jewel', the enzyme activity increased with the temperature up to about 40°C and between 60-70°C. In 'Beauregard' the absorbance increased from 0.35 at 30°C to 0.55 at 50°C, then decreased to about 0.2 at 60°C, and at 70°C was slightly above 0.2 . In 'Jewel' the absorbance increased from 0.2 at 30°C to 0.3 at 40°C, then decreased to 0.25 and 0.15 at 50°C and 60-70°C, respectively.

Hoover (1967) investigated the influence of activated native enzymes present in the roots of 'Goldrush', 'Centennial' and 'Nugget' by heating the material at between 71°C to 100°C for 60 minutes to cause starch hydrolysis. The material for this enzyme-activation technique could be freshly harvested or cured roots with any size and shape. Hoover (1966) technique for flake production was applied to starchy and uncured roots of 'Goldrush' cultivar. The steam injection was used for preheating the material to 79-81°C in order to obtain flakes of better quality. The puree was initially treated with a commercial enzyme and afterwards through a system of adding-back a certain amount of enzyme treated material. This method improved the organoleptic characteristics of the flakes. In sweetpotato flakes made by the enzyme-activation technique, temperature influenced the production of sugars. The response depended on the cultivar.

Another study using 'Nugget', 'Centennial' and 'Goldrush' cultivars was conducted by Hoover and Harmon (1967). They showed the effect of preheating on carbohydrate

concentration. Due to enzyme activation at temperatures between 71 °C to 100 °C for a period of time up to 60 minutes, sugar concentration increased, reaching the highest concentration at 79 °C and then decreased. Total sugars and maltose significantly increased in the first 10 minutes. Sucrose and glucose were present in lower concentrations and did not change much with the variation of conversion time and temperature. Sucrose concentration did not change with variation of the enzyme activation. In Indian cultivars, the highest enzyme activity was in the beginning of heating up to the gelatinization. Temperature and length of reaction were the main influencing factors for starch hydrolysis (Madhusudhan *et al.*, 1993).

CARBOHYDRATES AND SUGARS IN SWEEETPOTATOES

Carbohydrate composition of sweetpotato roots varies between fresh and baked conditions. Proportions depend on cultivar, environmental conditions and length of storage. The most common carbohydrates in sweetpotato roots are fructose and glucose (monosaccharides), maltose and sucrose (disaccharides), dextrins (oligosaccharides), and starch (polysaccharide). Other carbohydrates that are present in sweetpotato roots are cellulose, pectic substances, hemicellulose, maltotriose, inositol, raffinose, and stachyose. The variation of type and amount of sugars influence the rheologic characteristics of sweetpotato products (Kays, 1992; Howling, 1989; Collins and Walter; 1985).

CHANGES IN ALCOHOL INSOLUBLE SOLIDS (AIS) IN STORAGE AND DURING HEATING

Alcohol insoluble solids (AIS) is a major component of sweetpotato that includes starch. Its concentration in processed sweetpotatoes depends on root cultivar, size,

development stage, internal temperature, processing temperature and duration (Mandava, 1995; Picha, 1986b,d; Hammet and Barrentine, 1961). In sweetpotato roots endogenous enzymes, mainly α- and β- amylase, convert starch into dextrins and soluble carbohydrates. Picha (1986d) studied AIS during curing (10 days at 32°C and 90% RH) and storage (15.6°C and 90% RH) of six cultivars. AIS decreased in orange-flesh cultivars. In white-flesh cultivars AIS increased during four to 14 weeks of storage, and decreased in longer storage. In 'Jewel' roots, AIS decreased from about 19% to 13%, dry basis, during curing and 46 weeks storage at 15.6°C. AIS also decreased in 'Travis', 'Jasper' and 'Centennial'. It increased in 'Whitestar 'and 'Rojo Blanco' (white-flesh cultivar) proportionally to total sugars reduction. Picha (1986b) observed in baked roots of 'Jewel' that AIS content was 19.4% after harvest, decreased to 17.8% after curing, to 16.1% after 14 weeks storage, and up to 12.3% after 46 weeks storage. Hageninama *et al.* (1994) analyzed AIS changes during root germination and observed a decrease of 45% in 'Beauregard' and 52% in 'Porto Rico' during 35 days. AIS content in 'Beauregard' before germination was about 60 % dry matter. Other studies also referred to AIS reduction during curing and storage.

Mandava (1995) reported that AIS concentration was higher in raw roots than steamed roots and significantly different between cultivars. It was in average about 51%, dry basis, in 'Jewel' and 47%in 'Beauregard'. It was higher in raw roots than in cooked roots. In cooked roots AIS reduction rate depended on the heating time and size of the roots. In 'Jewel' before heating AIS was about 73% and 63% in small and large roots, respectively. After 40 minutes heating the AIS concentration content in 'Jewel' was reduced to 31% in small roots and to 26% in large roots. In 'Beauregard' AIS was reduced to 19%

in small roots and to 28% in large roots. Szyperski *et al.* (1986) studied AIS content in stored and non-stored 'Jewel' roots, pureed and preheated with steam injection at 105°C for five minutes. Part of the roots was treated with a commercial α- amylase and mixed with untreated samples at proportions of 0:100, 25:75, 50:50, 75:25, and 100:0, respectively. They observed that the AIS concentration is reduced by enzyme depending on proportion of enzyme-treated material and roots being stored or not. Samples from non-stored roots with zero and 100% enzyme-treated material had 62% and 26%, respectively. In samples from stored roots AIS concentration with zero and 100% enzyme-treated material was 48% and 28%, respectively. Total sugar content increased from about 26% to 30% in non-treated samples, and from 42% to 45% in 100% enzyme-treated samples, in non-stored and stored roots, respectively. This indicates that AIS was not different in non-stored and stored roots, particularly in samples with 75% enzyme -treated: 25% untreated material. Jenkins and Gieger (1957a,c) observed in 'Porto Rico' and 'Allgold' that AIS content was reduced and sugar content increased when the internal temperature of the root increased. AIS content was 72% in 'Porto Rico' and 62% in 'Allgold' in raw roots at 20°C, and decreased until about 30% at 65°C internal temperature of the root. In baked roots AIS was reduced to about one third during the first 30 minutes with little changes with longer baking.

CHARACTERISTICS OF SWEETPOTATO STARCH AND CHANGES DURING CONVERSION

Starch is one of the two most abundant carbohydrates in nature and it is a rich source of reserve energy. The starch granules, linked by hydrogen bonds, vary in size and shape. Starch is a homopolymer of α-glucose, existing in two different forms, amylose and

amylopectin. Amylose is a linear chain or unbranched component where the glucose molecules are linked in the α-1,4 positions. Amylose has a molecular weight ranging from 800,000 to 1 million Daltons. It is lower in cereal than in tuber starches, with the exception of potato that has 2.4 million Daltons. The amylopectin is a branched component where glucose units are linearly linked in the α-1,4 positions but the branches are linked in α-1,6 positions. Amylopectin has a molecular weight of several million Daltons. The different proportions of these two components, their molecular weights and their structures give different morphologies and characteristics to the starch of different species.

There are two types of starch, the transitory and the reserve starch. The first type of starch is formed in the leaves during daytime and converted to sucrose during night. The reserve starch is the one that exists in the sweetpotato storage. Amylose represents 70% in fresh roots. The amylose has a crystalline structure and is not stable in aqueous solutions like amylopectin. The size and shape of the granules and their distribution influenced the starch properties (Madamba *et al.*, 1975). The size of the starch granules may influence the enzymatic or acid conversion of starch being lower in large granules (Kays, 1992; Tian *et al.*, 1991; Howling, 1989; Bouwkamp, 1985; Collins and Walter; 1985).

The physicochemical characteristics of the starch granules are not only influenced by the genetic factor but also by the growing process of the crop in the field. The starch granules are water insoluble and may be isolated from the plant tissue without degradation. Starch gelatinization is the hydration and swelling process of the starch granules that cause the loss of the macromolecular structure and change the starch characteristics. The

gelatinization temperature is between 67°C and 75°C depending on the starch granules (Madhusudhan *et al.*, 1993; Tian *et al.*, 1991; Kennedy and White, 1988).

Starch gelatinization starts with the hydration at the hilum and continues to the outer layers of the granule. The granules swell, rupture and lose their integrity. Starch with high amylose content have higher temperature of gelatinization. The large granules gelatinize first, then the small granules. The hydration rate depends on the molecular weight and the length and branches of the starch components. It also depends on the starch source (Madamba *et al.*, 1973)

Walter *et al.* (1975) found that starch conversion rate during baking was 63-69 % in freshly harvested roots and 91-95 % in roots stored for 71 days. Starch and its conversion into sugars depended on cultivar, total solids, storage and cooking conditions. Baked products were used to define the quality of cooked sweetpotato products. Starch conversion and product quality was higher in baked than in boiled roots (Reddy and Sistrunk, 1980; Sistrunk *et al.*, 1954).

TOTAL SUGARS IN RAW AND COOKED SWEETPOTATO ROOTS

Determination of total sugars has been done in different cultivars, raw and cooked sweetpotato products, under different conditions. The increase of total sugars in cooked roots is because of maltose production (Morrison *et al.*,1993; Tsou and Hong, 1992).

Susheelamma *et al.* (1992) compared the composition of sugars from raw and processed roots obtained in the market. They observed an increase of 30-40% total sugars in processed roots. Morrison *et al.* (1993) worked with 'Jewel' and other cultivars, fresh, cured or stored at different conditions. Raw 'Jewel' had higher content of fructose, sucrose,

glucose and total sugars compared to the other cultivars. Only trace amounts of maltose were found in raw roots, and increased when the roots were baked, causing the increase of total sugars. Sugar content in raw and baked 'Jewel' was 0.05% and 18.5% maltose, 12.5% and 7.76% sucrose, 4.54% and 2.57% glucose, 3.43% and 2.25 % fructose, and 20.6% and 31.0% total sugars, respectively.

Van Den *et al.*(1986) verified with Philippino cultivars that the amount of sugars depended not only on cultivar but also on the method of analysis. In raw roots, the content of sugars, determined by high-performance-liquid-chromatography (HPLC), was about 4-17 mg/g, dry weight, fructose, 4-21mg/g glucose, 43-142 mg/g sucrose. In cooked roots it was 1-18mg/g fructose, 2-43 mg/g glucose, and 12-114 mg/g sucrose. The variation was significant among cultivars. Sugar concentration determined by HPLC was higher than that determined using gas chromatography (GC). Hageninama *et al.* (1994) observed that total sugars did not change significantly during 35 days of root germination, being about 20- 25% dry matter in both 'Beauregard' and 'Porto Rico' cultivars. Horvat *et al.* (1991) determined in 'Jewel' the amount of total sugars was 6.21%, fresh weight, in raw roots and 9.31% in baked roots. Walter (1987) observed the amount of total sugars was 10- 16% (fresh weight) in cured and uncured roots after 68 days storage, slightly more than the concentration of 9-10 % in fresh harvested roots. Walter *et al.* (1975) found the sugar content to be 2% fresh weight in freshly harvested roots and increased to 6% after 71 days. Wu *et al.*(1991) determined glucose, fructose, sucrose, and maltose in baked 'Jewel' roots of large size with three months storage. The total was 15.2%, dry weight, and can be considered as total sugars. After curing the roots had 15.06% total sugars. Schwartz *et al.*, (1987) referred to

sugars depending on processing method, cured 'Jewel' roots had about 32%, dry weight, in raw stage and 22% when fried. With other cultivars the results on storage and cooking may be compared with 'Jewel' or 'Beauregard'. It was also observed that total sugars increased with curing, storage and cooking in amounts that depend on cultivar, curing, storage, and processing conditions (Reddy and Sistrunk, 1980; Madamba *et al.*, 1977; Sistrunk, 1977; Hoover and Harmon, 1967).

IMPORTANCE OF MALTOSE IN COOKED SWEETPOTATOES

Maltose is formed by two glucose molecules, linked by 1,4-α- glycosidic bond. It is the disaccharide included in the reducing sugar group as a product of amylolytic breakdown of polysaccharides during malting or digestion in the animal body. Maltose may be detected in trace amounts in raw sweetpotato roots. During the enzymatic hydrolysis of starch, 80% of amylose converts into maltose (Lee, 1983). Beta-amylase breaks the penultimate glycosidic bond from the nonreducing end of starch into maltose and "limit dextrins" containing α-(1,6)-glucosidic bonds that are not hydrolyzed by α- or β-amylases. Maltose is the predominant sugar in, and gives sweetness to cooked roots. Compared to other sugars maltose is about three times less sweet than sucrose, two times less than glucose and five times less than fructose. Sweetness of cooked sweetpotatoes is due to the formation of maltose and short-chain branched oligosaccharides with low molecular weight (limit dextrins) as a result of starch hydrolysis by α- and β-amylases (Deobald *et al.*,1968, 1969; Ikemiya and Deobald, 1966; Morrison *et al.*,1993; Koehler and Kays, 1991; Bradbury *et al.*,1988). Maltose contributes to the aroma and color of cooked sweetpotato products. Enzymatic and thermal reactions cause caramelization, a thermal degradation of sugars, and

Maillard reaction between reducing sugars from starch hydrolysis and proteins and/or amino acids. Maltose has been also considered the precursor for volatiles production during baking, which give the strong and specific flavor to sweetpotato cooked products. This flavor is the main reason for the reduction of sweetpotato consumption in some countries. 'Jewel' had large amounts of volatiles (Sun *et al*, 1995, 1993; Horvat *et al.*, 1991; Jenkins and Gieger, 1957b).

Maltose production depends on one or more combined factors that include cultivar, curing and storage, peeling, and cooking method and temperature. These factors have been also studied in other cultivars rather than 'Jewel' and 'Beauregard'. Mandava (1995) did not find maltose in raw roots but in cooked roots. The maximum maltose content was about 28% (dry weight basis) in small roots of 'Jewel' and 'Beauregard' cooked for 5 minutes, in large 'Jewel' roots cooked for 40 minutes and in large 'Beauregard' roots cooked for 20 minutes. The average of maltose content was 16.08% in 'Jewel' and 17.99% in 'Beauregard'. The average of maltose content of 'Jewel' and 'Beauregard' roots by size showed that small roots had 19.42% and large roots had 14.42%. Morrison *et al.* (1993) analyzed sugars in 'Jewel' and other cultivars, in fresh, cured, and stored roots. Maltose content in raw and baked 'Jewel' was 0.05% and 18.5%, dry basis, respectively. Picha (1986b) stated that maltose content in baked 'Jewel' (g/ 100g fresh baked roots) was 9.70 after harvest, decreasing to 7.06 after curing, increasing to 8.32 after four weeks storage and then decreasing again after 14 weeks storage to 7.55 and finally up to 4.81 after 46 weeks storage. Maltose content of 'Jewel' was comparable to 'Jasper', higher than 'Travis' but lower than 'Whitestar', 'Rojo Blanco', and 'Centennial'. In a previous study (Picha

1985) maltose was not detected in raw roots but in baked roots at a concentration of 7.55% in 'Jewel' roots stored for three months at 15.6°C. Horvat *et al.* (1991) determined that the maltose concentration in 'Jewel' roots was 0.03% in raw and 3.81% in baked roots, fresh weight.

(Walter *et al.*, 1976) found that peeling method influenced maltose production which is related to enzyme activity. The hand peeled roots, non-heated, had 0.1%, dry basis, of maltose. After 20 and 60 min of steam injection at 103°C, maltose content increased to 0.7% and 0.6%, respectively. Lye-peeled raw puree had 15.6- 18.7% of maltose. In a previous study, Walter *et al.*(1975)observed that maltose production during cooking was high before the center of the root reached temperature of gelatinization (68-73 °C) which suggests that starch conversion occurs earlier in the heating process. They found the amount of 14.2 %, fresh weight, of maltose in baked 'Jewel' roots after harvest and it was reduced to 9.9% in baked roots after 71 days storage. Maltose also decreased in stored roots of 'Centennial', 'Porto Rico Mutant', and 'Pelican Processor'. Gore (1923) reported 0.23% maltose in raw roots with an increase to about 10-20% in steamed or baked roots of two another cultivars. Susheelamma *et al.*(1992) did not detect maltose in raw roots purchased in the local market and its content increased to 0.1-0.8% in processed roots.

Deobald *et al.* (1969) showed that maltose production increased in preheated roots. Maltose in a raw grind was 6.95% dry basis, 30.95% at conversion temperature (75- 78°C), and 39.07% after cooking at 100°C. Comparing non-preheated with preheated method, maltose was in a raw grind 5.82% and 16.41%, respectively. At conversion temperature and

after cooking maltose content was not significantly different before and after preheating, being about 31-41 %.

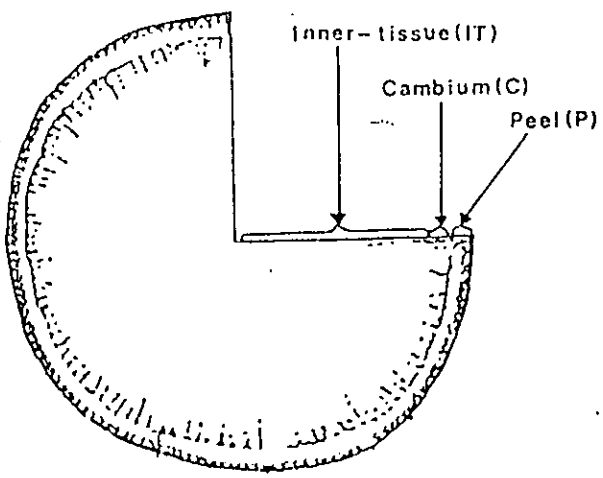
The amount of maltose produced was lower when the roots were cooked in microwave comparing with the convection oven (Sun *et al.*, 1993). It was suggested that this is due to the short conversion time in the microwave where the heat penetrates through the root faster than in a convection oven. Microwaving reduces the time between gelatinization and enzyme inactivation (Horvat *et al.*, 1991). Picha (1985) reported no difference in maltose and other sugars in roots cooked in a microwave or in convection oven. Bradbury *et al.* (1988) mentioned that different cooking methods influenced the root composition. Maltose did not change significantly in boiled, steamed and baked roots, being about 6.4-6.9% fresh weight. Cooking temperature also influenced maltose production. Maltose content increased from 0.03% to 4.33% fresh weight of 'Jewel' when cooking temperature increased from 25 to 80°C, respectively. Temperatures above 80°C reduced maltose content (Sun *et al.*, 1994).

MATERIAL AND METHODS

SELECTION AND PROCESSING OF 'BEAUREGARD' AND 'JEWEL' ROOTS

The cultivars used in this research were 'Jewel' and 'Beauregard', grown at Burden Farm of the Louisiana Agricultural Experimental Station, Baton Rouge, Louisiana, USA. The roots were harvested on September 15 and October 19, 1995, cured for 10 days at 30°C and 90% relative humidity, and stored for 100 and 135 days, at 15°C and 85% relative humidity. For the experiment roots were selected based on their size: large (6.35-8.89 cm diameter equivalent to 2.5-3.5 inches) and small (1.9- 3.8 cm diameter equivalent to 0.75- 1.5 inches) and processed on January 17-28, 1996.

The processing of roots consisted of washing with tap water, rinsing, and hand peeling 64 roots (four roots of each of two cultivars stored for each length of storage and of each size) with synthetic scrub sponge. The outer layer or cambium (about three mm width) was removed with a knife (Figure 2). The zone tissues were cut into pieces and grinding separately the cambium and the remaining tissue or inner tissue, using a food processor (Le Chef, Sunbeam Corporation, Chicago, Illinois). From the raw ground material, 256 samples were weighed (Mettler PE 360 delta range, Mettler Instrument Corporation, Highs town, New Jersey) in plastic boats and covered with aluminum foil (128 samples of 10g each) or in plastic tubes and covered with lid or paraffin paper (128 samples of 1g each). The remaining ground material was packed into medium zipped transparent plastics and stored in a freezer.



(Source: Noda *et al.*, 1992)

Figure 2. Cross-section of sweetpotato root with indication of zones separated in this study: P- peel, C- cambium, and IT- inner tissue.

CHEMICAL ANALYSIS OF SWEETPOTATO ROOTS FOR SOLUBLE SUGARS

The quantitative analysis of sugar in raw and cooked samples was determined by high- performance-liquid-chromatography (HPLC) using isocratic technique (Picha, 1985). The preparation of the extract from uncooked and cooked samples started with thawing the weighed frozen material in a refrigerator.

The preparation of the 10 g or 1 g samples differed in the heating (hot plate heating for 10 g samples and waterbath heating for 1 g samples) and filtration (vacuum filtration for 10 g samples and paper filtration for 1 g samples) steps. Smaller glassware was used for 1 g samples to avoid losses. The ground material for cooked and uncooked samples was processed following the same procedures with exception of the incubation step for half samples. The samples kept in plastic boats were transferred to 50 ml plastic tubes. The procedure was as follows:

1) Incubation was done by placing the tubes in a wire test tube rack in the water-bath (Blue M, Electric Company, Blue Island, Illinois) at 70 °C for 1 hour and then cooled.

2) Homogenization of both cooked and uncooked samples (in 50 ml plastic tubes or poured into 50 ml glass beakers) was done for 1 minute at high speed, using a Virtishear 45 homogenizer (The Virtis Company, Inc. Gardiner, New York). Aqueous ethanol (80%) was used for dilution of the samples for better homogenization. The homogenized product or slurry (from 10 g samples) was poured into labeled 250 ml beakers, using 80% alcohol to remove completely the material from the tube or 50 ml beaker.

3) The 10 g slurries were boiled on hot plates (Lab-Line Instruments, Inc., Melrose Park, Illinois; and PS- Precision Scientific (subsidiary of GCA Corporation, Chicago,

Illinois), for 15 minutes. Each slurry was carefully and repeatedly stirred with a metallic spatula, using 80% ethanol to remove the slurry from the beaker's internal wall, to avoid the overcooked deposit. Each beaker was covered by a watch glass to reduce spattering during boiling. At the end of the boiling step, the volume of the slurry was about 10 ml. The 1 g slurries were boiled in the water-bath (Blue M, Electric Corporation, Blue Island, Illinois) instead of the hot plates, for 15 minutes.

4) After 24 hours the boiled 10 g slurries were vacuum filtered for 5- 10 minutes into plastic filtration units (bottle and filter), through Whatman # 4 paper (Whatman International Ltd., Maidstone, England) previously weighed (Mettler PM 4600 DeltaRange, Mettler Instrument Corporation, Highstown, New Jersey), removing all residues from the beaker with 80% ethanol. The 1 g slurries were filtered through smaller glass funnels with folded paper filter Whatman # 4, previously weighed and labeled with sample code, into 10 ml graduated cylinder.

5) The filtrates from 10 g samples and the alcohol used to rinse the filtration units were poured into 100ml volumetric flask s using a glass funnel and brought up to 100 ml volume with 80% ethanol. The filtrates from 1 g samples were made to a final volume of 10 ml with 80% alcohol, including the amount used to rinse the tubes.

6) All the extracts were gently mixed by inversion and placed into labeled 20 ml disposable scintillation vials (Cole-Parmer Instrument Company, Niles, Illinois).

7) Each extract was syringed/ filtered (5 ml syringe #1603, Becton Dickinson and Company, Frankling Lakes, New Jersey) using a Nalgene 0.45 μ filter membrane (# 199-2045, 25mm, Nalge Company, Rochester, New York) into a labeled 1 ml scintillation vial

(223682- CMS, Wheaton Scientific, Millville, New Jersey). Each vial was capped with a Teflon lined crimpcap for later injection into a high-performance-liquid-chromatography (HPLC) (Waters Associates, Milford, Massachusetts).

The HPLC equipment included a Waters pump (model 501), an autosampler (model LC-241, Dynatech Precision Sampling, Baton Rouge, Louisiana) fitted with a 10 µl sample loop, and a Waters refractive index detector (model 410). The analytical column was a SupelCosil™ LC-NH_2 25 cm x 4.6 mm (Supelco Inc., Belefonte, Pennsylvania). The mobile phase was acetonitrile (NA 1648, Mallinckrodt Inc., Paris, Kentucky):deionized distilled water (75:25). Its flow rate was 1.0 ml per minute. The running time was 17 minutes. The standard was injected as the first sample and after each nine samples. Individual sugars were identified and quantified based on retention time and peak area of the sugar standards- 1.5% fructose, 1.5% glucose, 4% sucrose, and 8% maltose. Analytical grade sugars (Sigma Chemical Company, St Louis, Missouri) were prepared for standards following the same procedures as root sample preparation. The HPLC output was evaluated by means of Waters Maxima 820 software and included a chromatogram of individual sugars, and a table of sugar concentrations expressed on a fresh weight basis. The sugar concentrations were presented as percentage of fresh weight (Appendices 1-7).

DETERMINATION OF ALCOHOL INSOLUBLE SOLIDS (AIS) IN 'BEAUREGARD' AND 'JEWEL' ROOTS

The sample for analysis of Alcohol Insoluble Solids (AIS) is obtained from the filter residue of the sugar extraction. Each sample was dried for 24 hours, in a vacuum dryer (National Appliance Company, Portland, Oregon) at 50°C, 12 KPa Hg. The dried filter

with the residue was weighted (Mettler PM 4600) and filter weight was subtracted (Picha, 1985). The results of AIS were expressed as a percentage of fresh sample.

ANALYSIS OF ALPHA- AMYLASE IN CAMBIUM AND INNER TISSUE OF SWEETPOTATO ROOTS

The method used for α- amylase was adapted from Walter and Purcell (1973). A buffer solution was prepared with 2.839 g of sodium biphosphate- Na_2HPO_4 (Sigma S-0875, Sigma Chemical Company, St. Louis, Missouri) diluted in distilled water and brought up to 100 ml in a volumetric flask, and 5.999 g of sodium monophosphate- NaH_2PO_4 (Sigma S-0751) diluted in distilled water to 250 ml in another volumetric flask, and stopped with paraffin paper. The two solutions were each mixed by inversion movement to obtain a homogeneous solution. From these solutions, 6.15 ml of 0.2M Na_2HPO_4 and 43.85 ml of 0.2 M $NaH_2\ PO_4$ were mixed in a 100 ml volumetric flask, forming a 0.2 M buffer solution and refrigerated at 4°C. This buffer solution was diluted to 0.02 M by mixing 10 ml with distilled water bringing it up to 100 ml in a volumetric flask. The pH of the final solution was adjusted to 6.0 with 0.1N HCl and measured by Zeromatic IV pH meter (Beckman, Beckman Instruments, Inc., Irvine, California). A 5% solution trichloroacetic acid- Cl_3CCO_2H (EM # TX 1045-3, EM Science, Gibbstown, New Jersey) was diluted with distilled water to 100 ml in a volumetric flask. A standard of 0.1 M solution of cupric sulphate- $CuSO_4$ (Sigma # C- 7631, Sigma Chemical Co., S.Louis, Missouri) was prepared by diluting 2.497 grams in distilled water to 100 ml in a volumetric flask.

The frozen sweetpotato material was thawed in the refrigerator, and hand-squeezed using a double layer of cheesecloth. The extracted or crude juice was collected in a glass beaker or a plastic centrifuge tube. The crude juice was centrifuged for 10 minutes at 4°C and 7000 rpm (Sorvall RC-5B Refrigerated Superspeed Centrifuge, Du Pont Instruments, Du Pont Company, Newton, Connecticut). The supernatant, which contains the enzyme, was poured into other labeled tubes with lids and kept in a cooler at 4°C. At the time of enzyme analysis, the tubes were removed from the freezer and kept in a bowl with ice to maintain a cool temperature.

Substrate slurry was prepared by mixing 0.7g of Amylopectin Azure (Sigma # A-6808) weighed in a 100 ml glass beaker, 0.105 grams sodium chloride- NaCl (EM # SX 0420-1, EM Science, Gibbstown, New Jersey) weighed in a plastic boat, and 35 ml of the previously prepared 0.02 M buffer solution. The amount of each mixture was enough for 12 tubes which corresponded to 4 juice samples- 2 replications and 1 blank each. The solutions were carefully and continuously mixed using a 1 ml pipette and 2.7 ml of each was put into a labeled plastic tube. The metallic rack with the tubes was placed in the waterbath at 60°C for 15 minutes. An amount of 1.2 ml of 5% trichloroacetic acid was pipetted into the blanks to stop the reaction. The tubes were covered with lids, vortexed (Cyclo-mixer, Clay-Adams, Inc.) and put them back into the rack. After one minute, 0.3 ml of each stirred juice sample was pipetted into the corresponding blank and into the two replicates. All tubes were vortexed after covering with their lids. The pipette tip was changed for each juice sample. After 15 minutes incubation, the blank was removed,

vortexed and put into another rack; for replications, 1.3 ml of trichloroacetic acid was pipetted into each tube before removing from the waterbath followed by vortexing.

Afterwards, each sample was centrifuged in a small centrifuge at speed 5 (International Clinical Centrifuge, Scientific Products, Evanston, Illinois) for 3 minutes. The supernatant was filtered through Whatman #2 filter in a glass funnel, placed on a holder, into plastic cuvettes. The enzyme activity was measured by reading the absorbance of the filtrate in a spectrophotometer (DU- 65 Beckman, Beckman Instruments, Inc., Fullerton, California) at 595 nm wavelength. For each run, the spectrophotometer was calibrated with a buffer solution followed by the $CuSO_4$ standard. The α-enzyme activity was expressed in APA (amylase) units/ ml of juice, given by the formula ($Abs._{(595nm)}$sample - $Abs._{(595nm)}$blank)/ $Abs._{(595nm)}$ 0.1M $CuSO_4$ (Walter and Purcell, 1973).

EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS

The experiments consisted of 256 samples - duplicate of samples prepared from 4 roots within each population defined by 2 cultivars ('Jewel' and 'Beauregard') x 2 storage periods (three and four months) x 2 root sizes (small and large) x 2 zones (cambium and inner tissue) x 2 sample treatments (raw or unprocessed and processed). The sugars and AIS analysis were each done in duplicate. For the α- amylase analysis, each sub-sample was analyzed in duplicate (for an average of the two readings) and compared with a blank.

The roots were nested within cultivar, length of storage, and size. The factor zone was crossed with the other factors. The root effect was considered random since they were randomly chosen from a population of roots of the same cultivar, length of storage, and size. The remaining factors were considered fixed. The data were analyzed by an ANOVA

(analysis of variance) mixed model, with root as a random factor, using SAS PROC mixed procedure (SAS, 1995). The following steps were carried out: (1) Diagnosis of data meeting the assumptions required for ANOVA models; (2)Test for possible interactions among factors with relevant plots; (3) Test for main effects. A family wise error rate of 10% was used in multiple comparisons of interest with Bonferoni Adjustment. The residuals were analyzed by examining the plot of residuals versus predicted values, the box-plot, stem and leaf plot, and the normality plot. The interactions among factors were assessed by comparing least square means (lsmeans) using the slice option.

The statistical analysis was based on 256 observations of raw and cooked samples for AIS, total sugars, sucrose, fructose and glucose. The analysis of α-amylase was based on 128 observations corresponding to raw samples assuming that the enzyme is inactivated by heating. The analysis of maltose was performed in 128 cooked samples because it is not expected to occur in raw roots. The results are presented as least square means (lsmeans) with standard error.

RESULTS AND DISCUSSION

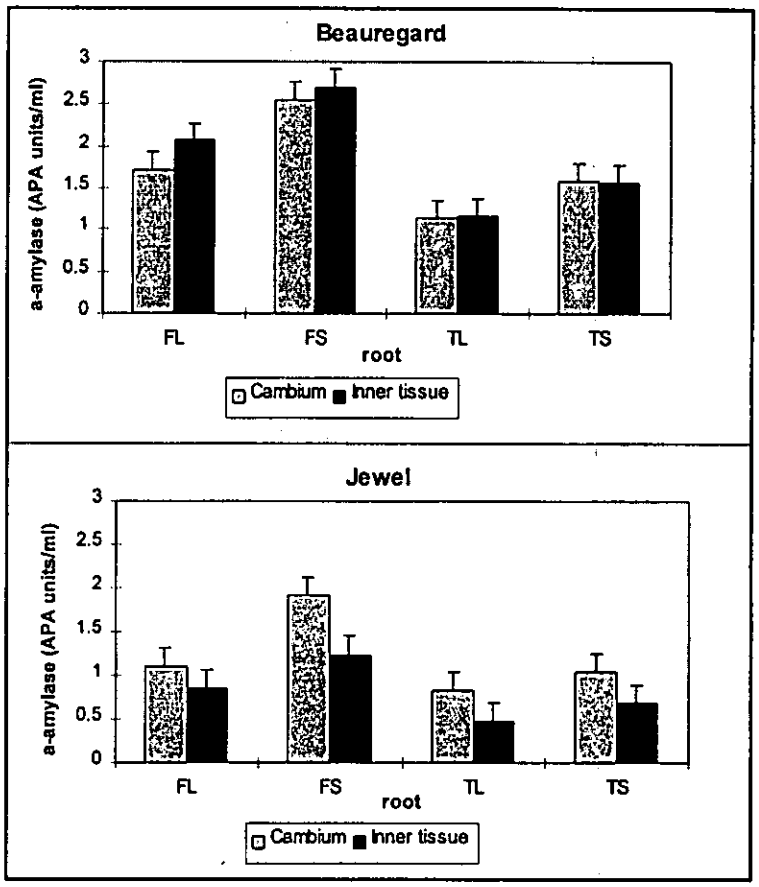
The results are presented in a format that discusses the individual variables (alpha-amylase, alcohol insoluble solids, and sugars) with emphasis on cultivar, storage, size, zone, and processing. The effect of these factors and their interactions was assessed at the 5% level of significance as shown in Table 2.

ALPHA- AMYLASE ACTIVITY IN CAMBIUM AND INNER TISSUE OF SWEETPOTATO ROOTS

The results of α-amylase activity in sweetpotato roots show that the enzyme was influenced by cultivar, storage, size and zone. The α-amylase activity ranged from 0.48 to 2.71 APA units/ml of juice, in the inner tissue of large roots of 'Jewel' stored for three months and in the inner tissue of small roots of 'Beauregard' stored for four months (Figure 3). Comparing cultivars the α-amylase activity was significantly ($p<0.05$) higher in 'Beauregard' than in 'Jewel' regardless of the zones. Within a cultivar, it may vary by zone. In 'Beauregard' roots, differences were not statistically significant between cambium and inner tissue. However, in 'Jewel' α-amylase was significantly ($p<0.05$) higher in cambium than in the inner tissue. Comparing the enzyme activity of both cultivars within zones, 'Beauregard' had significantly ($p<0.05$) higher α-amylase activity than 'Jewel' either in cambium or in the inner tissue. Alpha- amylase content in roots significantly ($p<0.05$) differed due to length of storage not depending on cultivars, sizes, and zones. The roots stored for four months had significantly ($p<0.05$) higher enzyme activity than roots stored for three months in the overall root population. Size was also a significant factor ($p<0.05$) with higher enzymatic activity in small rather than large roots of 'Beauregard' and 'Jewel'.

Table 2: Significant effects of cultivar, length of storage, size, zone, and processing on α-amylase activity and on concentration of alcohol insoluble solids (AIS), total sugars, maltose, sucrose, fructose, and glucose at $p<0.05$.

Factor	Alpha-amylase	AIS	Total sugars	Maltose	Sucrose	Fructose	Glucose
cultivar	x			x	x		x
storage	x				x	x	
size	x			x			
zone	x		x	x		x	x
cook	x	x	x	x	x		
cult*stor						x	
cult*size			x		x	x	
stor*size		x			x	x	x
cult*zone	x	x	x	x	x	x	
stor*zone		x			x	x	x
cult*size*zone				x			
cult*stor*size*zone		x				x	x
cult*cook		x	x		x		
stor*cook						x	
size*cook		x	x			x	
cult*stor*size*cook						x	
cult*size*zone*cook			x				
stor*size*zone*cook							x



F= Four months storage L= Large roots
T= Three months storage S= Small roots

Figure 3. Alpha-amylase activity (expressed as least square means) in raw cambium and inner tissue of small and large 'Beauregard' and 'Jewel' roots, stored for three and four months, with a standard error of 0.21.

The results obtained in 'Jewel' in which α-amylase activity was higher in cambium than in inner tissue were similar to the results from the Hagenimana *et al.*(1994) study with roots of 'Beauregard' and 'Porto Rico' cultivars, and from Hagenimana *et al.* (1992 a, b) study with 'Jewel', 'Regal', 'White Delight' and 'Porto Rico' cultivars. They were opposite to the Ikemiya and Deobald (1966) study of 'Goldrush' cultivar, which stated that α-amylase activity was higher in inner zone than in cambium.

The lack of differences of α-amylase activity between the zones of 'Beauregard', has not been reported previously. Hagenimana *et al.* (1994) studied enzymes in roots throughout the germination process of sweetpotato roots using the chromogenic method (based on hydrolysis of amylose azure), and studied the concentration of enzymes by zones using the immunological detection (tissue-print imunoblotting). The α-amylase activity, measured in Units/ 100 g dry matter (U), in 'Beauregard' was concentrated in the outer zone on the third day of the germination (400 U) and spread gradually into the inner tissue (two-fifths of the root) during following nine days, but did not reach the core tissue of the root even after 50 days. The maximum activity of α-amylase was at day 25 of germination with 1500 U, decreasing afterwards to about 700 U. Alpha-amylase was not detected in the peel or periderm and in the core tissue. Beta-amylase was uniformly distributed throughout the root with variations of enzyme activity during the germination period.

Previously, Hagenimana *et al.* (1992a,b) prepared a crude extract of whole root, considered the first purification step in the production of antibodies used for the detection of enzymes from tissue prints. The α-amylase activity was higher than β-amylase activity. For example in 'Regal' cultivar α-amylase activity was 0.296U/ml compared to 506.7

units/ml of β-amylase. They also observed that purified α- and β-amylases did not hydrolyze native starch granules after one hour of incubation at different temperatures (40-80°C), but boiled starch granules were hydrolyzed at rates comparable to those found when soluble starch was the enzyme substrate. The enzyme activity, measured in U/g fresh root tissue (amount of enzyme liberating a quantity of colored, soluble material corresponding to 2.5 absorbance units at 595nm from 54 mg of amylose azure under defined assay conditions), of 'Jewel', 'Regal', 'White Delight' and 'Porto Rico' cultivars. They observed that α- amylase activity was higher in the outer zone of the root- periderm, laticifer and cambium (cambium of present study) for all cultivars. This was correlated with the higher concentration of the enzyme in the same zone. In 'Jewel' the α-amylase activity was three times more in cambium than in inner tissue. 'Jewel' had the lowest enzyme activity of the four cultivars. Beta-amylase activity was higher in the inner tissue although its presence was detected in other zones of the root. They concluded that α- amylase, being a thermostable enzyme, might be the reason for rapid starch hydrolysis and discoloration of the outer tissues of the root during lye peeling.

Ikemiya and Deobald (1966) observed that α- amylase activity in 'Goldrush' cultivar was higher in the middle (14.7 SDU/ml) and innermost (17.0 SDU/ml) tissues of the root (inner tissue of the present study) than in the cork layer (8.22 SDU/ml) (cambium of the present study). The enzyme activity was measured in saccharifying activity (mg of maltose produced by 1 ml of pressed juice per minute at 35 °C, from 15 ml of 2% soluble starch solution, expressed in SDU- sweetpotato dextrinizing units/ml). Beta-amylase activity was higher in the core tissue.

Alpha- amylase activity was influenced by storage. Several studies on specific cultivars reported comparable results, with variations depending on the cultivar, storage and processing conditions and probably the method and conditions of analysis. There was always an increment of enzyme activity up to an optimum point after which it decreased (Liu, 1995; Morrison *et al.*, 1993; Walter *et al.*, 1975; Deobald *et al.*,1969; Ikemiya and Deobald, 1966).

'Beauregard' had higher enzyme activity than 'Jewel'. Similar results were found by Liu (1995). In his study the α-amylase activity after three months storage was about 0.29-0.34 U/g in 'Beauregard' and about 0.21 U/g in 'Jewel'. In 'Beauregard' it was 0.29U/g at harvest and curing time, then decreased to 0.28 after one month storage, followed by progressive increase, up to about 0.29-0.34 U/g during the three following months. In 'Jewel' the activity was about 0.23 U/g at harvest and curing time, then decreased to 0.2 after one month storage, increasing again to about 0.21 U/g, remaining the same during in the following three months storage. 'Jewel' was the lowest within the four cultivars. Morrison *et al.*(1993) studied the α-amylase activity in "Jewel', 'Sumor', '99', and '86'. Measured as absorbance at 595nm, the enzyme increased from fresh harvested roots up to 6 absorbance units at 90 days storage, when it reached the maximum absorbance, and then decreased to 1.5 absorbance units at 120 days storage.

Walter *et al.*(1975) studied six cultivars ('Centennial', Jewel', 'Porto Rico', 'Nugget', Australian Canner', and Pelican Processor'). They observed that α- amylase activity (in APA amylase units per ml of sweetpotato juice at 60°C during 15 minutes reaction) increased steadily with time at different rates. The α- amylase activity was 1.2

APA units at harvest, 1.9 and 5.6 APA units after 20 and 45 days storage, respectively for 1971 crop. In 1972, it was 0.6 APA units at harvest, and 6.5, 10.9 and 22.7 APA units after 31, 48, and 71 days storage.

Hiranpradit and Lopez (1976) measured the activity of commercial α- and β-amylase added to samples of 'Centennial' cultivar, at temperatures from 4 to -23 °C. The results indicated the enzymes were still active at 4 °C in the extracts from non-cured roots stored for 14 days and in cured roots stored for 28 days. Both enzymes decreased significantly after 42 and 56 days storage and when the storage temperature decreased. They were stable in roots stored at temperatures from -13 to -23 °C.

Deobald *et al* (1971) observed in 'Goldrush' that α-amylase activity was less than 0.5 SDU in fresh harvested roots, 6 SDU in cured and 8 SDU in uncured roots after 65 days storage. In Deobald *et al.*(1969) the α- amylase activity was 0.43, 0.47, and 0.92 SDU/ml after 3, 4, and 7 days storage, respectively in fresh harvested, non-preheated roots. The enzyme activity decreased to 0.21, 0.39, and 0.36 SDU/ml on the same days in preheated samples (in waterbath at 60 °C for 20 minutes). In Deobald *et al. (*1968) the enzyme concentration in fresh roots increased from about 0.30 to 0.40 SDU/ml on the first three days storage, than increased rapidly to about 0.5 and 0.9 after 4 and 7 days storage. The α-amylase activity increased from 3.4 SDU /ml 4 days after harvest to 7.5, 10.4, and 20 SDU/ml after 95, 161 and 301 days, respectively (Ikemiya and Deobald, 1966).

Size was a significant ($p<0.05$) factor that influenced the enzyme activity of the root population, small roots had significantly ($p<0.05$) higher enzyme activity than large roots. It may be related with the chronologic age that influences the physicochemical

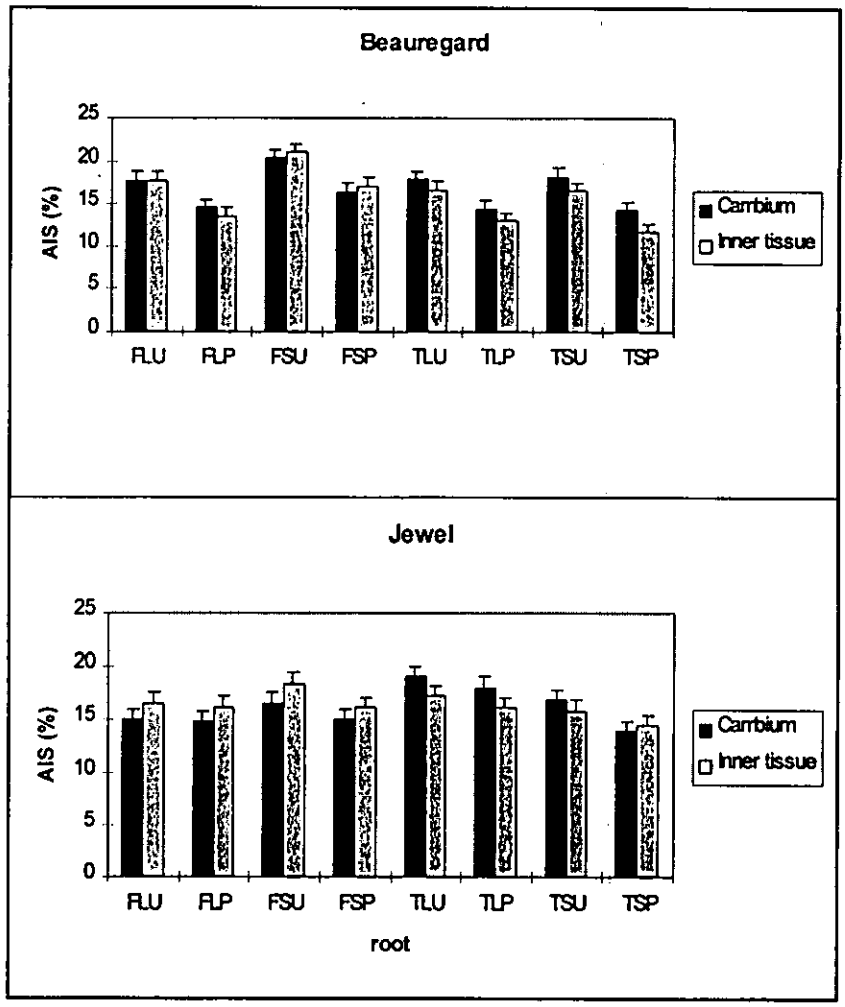
characteristics of the roots. Small roots are assumed to be younger or late-formed roots (Noda *et al.*, 1995; Takeda *et al.*, 1986; Scott and Bouwkamp, 1975).

CONTENT OF ALCOHOL INSOLUBLE SOLIDS (AIS) IN 'BEAUREGARD' AND 'JEWEL' ROOTS

Statistical analysis showed variation among roots of the same type and between type of roots. AIS concentration depended on cultivar, storage, size, zone, and heating at different levels, ranging from 11.7% fresh weight in cooked inner tissue of small 'Beauregard' stored for 3 months to 21.01% in raw inner tissue of small 'Beauregard' stored for 4 months (Figure 4).

Cultivar, storage, size, and zone did not affect individually the AIS content but they were significant when the factors were combined. AIS was not significantly ($p<0.05$) different between 'Beauregard' and 'Jewel'. Within each cultivar there were some differences. In 'Beauregard' AIS was significantly ($p<0.05$) higher in the inner tissue of small roots than in the large roots stored for 4 months. The inner tissue of small roots had significantly higher AIS in roots stored for 4 months compared to roots stored for 3 months. AIS was higher in the cambium than in the inner tissue of large and small roots stored for 3 months. In 'Jewel' roots, AIS in the cambium of roots stored for 4 months was significantly higher ($p<0.05$) than in roots stored for 3 months. The cambium of large roots stored for 3 months had significantly higher AIS than that of small roots.

The content of AIS depended on size of the roots combined with cultivar, zone, and storage. It was lower in the inner tissue and higher in the cambium of large than in small roots of 'Beauregard' stored for 4 months and 'Jewel' stored for 3 months, respectively.



F= Four months storage L= Large roots U= Uncooked
T= Three months storage S= Small roots P= Cooked

Figure 4. Concentration (% fresh weight) of alcohol insoluble solids (AIS) (expressed as least square means) in raw and cooked cambium and inner tissue of small and large 'Beauregard' and 'Jewel' roots, stored for three and four months, with a standard error of 0.99.

AIS content in the cambium of large and small roots was not significantly different in 'Beauregard' stored for 4 months and in 'Jewel' stored for 3 and 4 months. In the inner tissue the concentration was not significantly different between large and small roots of 'Beauregard' stored for 3 months and 'Jewel with 3 or 4 months storage.

Mandava (1995) reported that AIS content was higher in 'Jewel' than in 'Beauregard', 50.84 and 47.00%, dry basis, respectively. Differences in results may be due to different sample type, processing method, temperature and duration. In her study, samples were lye-peeled, steamed for 40 minutes before mashing. In this research, samples were hand-peeled and divided by zone before grinding and cooking for one hour.

Size influenced AIS content significantly depending on the factors of cultivar, length of storage , root zone and processing. Small roots of 'Beauregard' and 'Jewel' had more AIS than large roots. Hoover and Stout (1956) referred to the influence of size cooking and consequently product characteristics. Cooking time and heat penetration depended on root size, and may have influenced the starch conversion.

The influence of zone in AIS reduction was observed by Hagenimana *et al.*(1994) in their study with germinated 'Beauregard' and 'Porto Rico'. They considered that enzymes influenced changes during germination, such as AIS and starch reduction. Alpha-amylase, synthesized and concentrated in the outer zone of the root, increased after the 9th day of germination and migrated to the inner tissue during germination. This study indicated how zone may be an important factor in starch conversion. Enzymes that are located differently in the cambium or inner tissue may cause variations in root composition when influenced by other factors.

Storage after curing influenced AIS concentration in roots depending on size and on zone. The interaction of length of storage and root size indicated that in roots stored for three or four months no variation of AIS was observed between large and small roots. Small roots had more AIS than large roots when stored for three months but there was no difference with four months storage. Large roots did not differ with length of storage. In the interaction of storage and zone, the results showed that in roots stored for three months AIS was higher in cambium than in the inner tissue. After four months it was the reverse, higher in inner tissue than cambium. Comparing zones, only in inner tissue is AIS significantly higher in roots stored for four than for three months, in cambium there was no difference. In inner tissue AIS was higher in small roots than in large roots of 'Beauregard' stored for three months and, in small 'Beauregard' roots stored for four months than in roots stored for three months. Cambium AIS was higher in large roots than in small roots of 'Jewel' stored for three months and, in large 'Jewel' roots stored for three than for four months. There was more AIS in cambium than in inner tissue of large or small 'Beauregard' roots stored for three months and, large 'Jewel' stored for three months. There was more AIS in inner tissue than cambium in large and small 'Jewel' roots stored for four months. AIS was not significantly different between raw roots of 'Beauregard' and 'Jewel' nor between large and small roots.

Cooking was also significantly different ($p<0.05$) in the interaction with cultivar and with root size. AIS reduction by cooking was due to starch conversion into soluble sugars. The influence of storage duration and conditions on AIS reduction was reported by Walter and Hoover (1984) and Walter and Hoover (1986).

AIS was significantly ($p<0.05$) different only between raw and cooked roots. Overall, raw roots had more AIS than cooked roots, 17.61% and 14.99% fresh weight, respectively. The results confirm similar findings in 'Jewel' and 'Beauregard' by other authors (Mandava, 1995; Picha, 1986b; Walter *et al.*, 1975; Woodroff and Atkinson, 1944) and in other cultivars (Van Den, 1986; McArdle and Bouwkamp, 1986; Scott and Bouwkamp, 1975; Jenkins and Gieger, 1957a,b). Although using different samples, results of this research are partly comparable with previous studies.

In summary, 'Beauregard' and 'Jewel' have no significant differences in AIS as cultivars. However, their size, zone, and length of storage may influence the cultivar selection. In 'Beauregard' AIS was higher in cambium of large or small roots stored for 3 months and in inner tissue in small roots stored for 4 months. In 'Jewel' AIS was higher in inner tissue than in cambium of large and small roots stored for four months and less in large roots stored for three months. As observed, AIS concentration in zones depended on combined factors. According to several studies, besides cultivar, storage, size, and processing, AIS variation also depends on concentration and activity of enzymes present in the root. Physicochemical characteristics may be considered in AIS reduction.

Madamba *et al.*(1973) suggested that starch granules of large size gelatinize before smaller granules; granules pasting temperature is high in peel, where younger cells are located; viscosity and starch breakdown is high in aged roots;and more amylose than amylopectin is present in young cells of any root tissue. 'Jewel' had smaller granules distributed in a narrow range, less amylose and higher gelatinization temperature (Noda *et al.*, 1995; Fujimoto *et al.*, 1972).

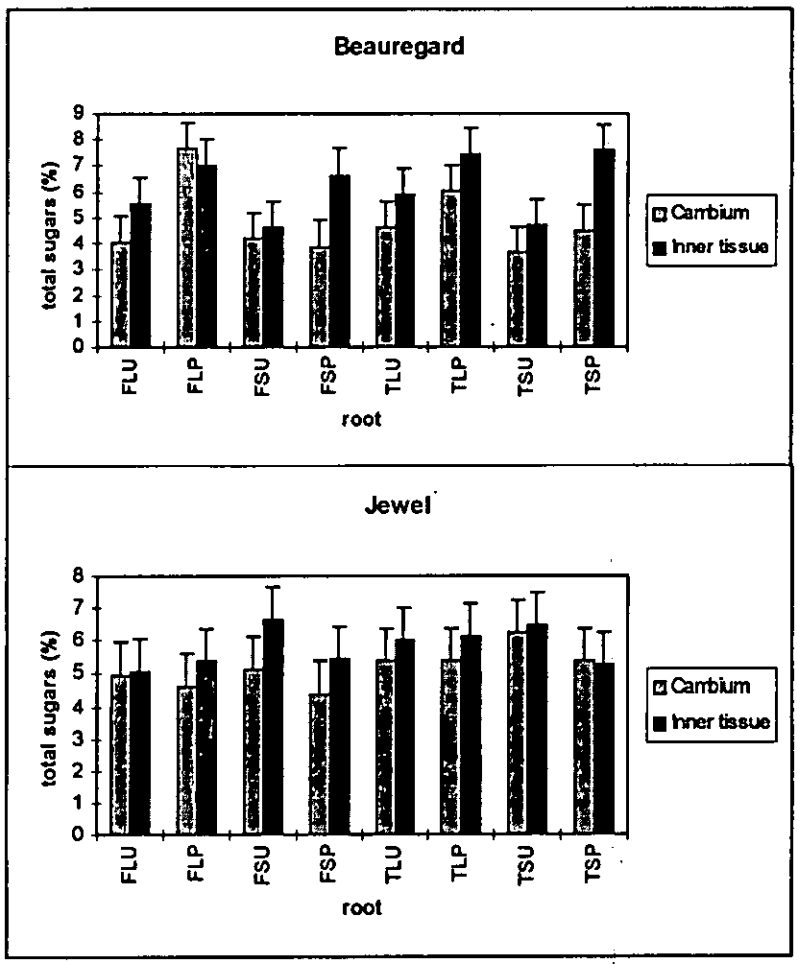
TOTAL SUGAR CONCENTRATION IN RAW AND COOKED CAMBIUM AND INNER TISSUE OF SWEETPOTATO ROOTS

Total sugar concentration refers to the sum of maltose, sucrose, glucose and fructose. Concentration of total sugars, given by least square means, ranged from 3.66% in raw cambium of small roots of 'Beauregard' stored for three months to 7.66% fresh weight of cooked cambium of large 'Beauregard' stored for four months (Figure 5).

Statistical analysis showed that total sugar content was not significantly ($p<0.05$) affected by storage but it was influenced by cultivar, root size and root zone. Within 'Beauregard', total sugars significantly ($p<0.05$) increased with processing in cambium and inner tissue of large roots and in inner tissue of small roots. In raw roots the total sugar of inner tissue was higher in large than in small roots. When cooked, large roots had significantly more total sugar than small roots in the cambium zone. In 'Jewel' roots, total sugar was significantly higher in raw cambium of small roots than in large roots. In inner tissue of small roots total sugar was significantly higher in raw than in cooked roots.

Comparing cultivars, total sugar was significantly higher in cambium and inner tissue of small raw 'Jewel' than 'Beauregard'. Total sugars in cooked inner tissue was higher in both small and large roots of 'Jewel' compared to 'Beauregard'.

In summary, raw 'Beauregard' large roots had more sugars than small roots, and the inner tissue contained more total sugar than the cambium. In raw 'Jewel' there was no variation in total sugars between zones in either large or small roots. Cooking increased total sugars in 'Beauregard'. Raw roots had less sugars than cooked in 'Beauregard. In cooked samples 'Beauregard' had more sugars than 'Jewel'. Cooked 'Beauregard' had



F= Four months storage
T= Three months storage

L= Large roots
S= Small roots

U= Uncooked
P= Cooked

Figure 5. Concentration (% fresh weight) of total sugars (expressed as least square means) in raw and cooked cambium and inner tissue of small and large 'Beauregard' and 'Jewel' roots, stored for three and four months, with a standard error of 0.51.

more total sugar than raw roots in both cambium and inner tissue of large roots. When cooked, large 'Beauregard' roots had more total sugar than small roots and the inner tissue had more sugar than cambium. Cooked small roots of 'Beauregard' had more sugars only in inner tissue. When cooked 'Jewel' sugars were reduced significantly in the inner tissue of small roots. Raw inner tissue had more sugars than cooked inner tissue of small 'Jewel'.

The results by zones show that total sugar is influenced by cultivar, size and processing. Considering that size is directly related with age (i.e., large roots equivalent to old roots) the results are not comparable to Scott and Bouwkamp (1975). They observed in 'Nemagold', 'Centennial' and 'Redmar' cultivars that total sugar decreased with the age of the root (period between planting and harvest) or with size. It was 11%(fresh weight) in 3 month roots decreasing to 5% in five months roots. Reddy and Sistrunk (1980) observed in different cultivars that total sugars did not differ due to root size.

Previous studies with 'Jewel' reported results on total sugars comparable to this research data. Picha (1986d) reported an increase of total sugars of raw 'Jewel' roots during curing and storage for 46 weeks. Between 14 and 22 weeks storage, the concentration of total sugars increased from about 22 to 23% dry weight. Sistrunk (1977) also observed increase of total sugars by storage in 'Centennial' and 'Georgia Jet' cultivars.

Mandava (1995) referred to individual sugars of 'Beauregard'(maltose, sucrose, fructose and glucose) whose sum, if considered as total sugars, was calculated to be 41.84% dry weight, higher than in 'Jewel' with 38.07%.

The influence of storage, cooking method, cultivar and type of product on total sugars of sweetpotato roots were described in previous reports. Morrison *et al.* (1993)

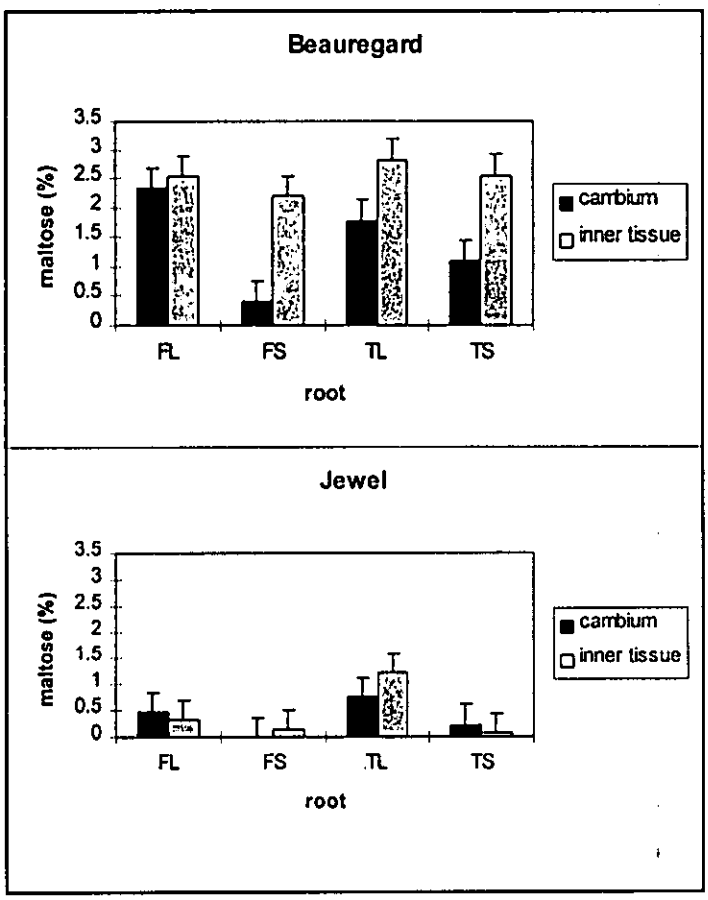
observed in raw roots of 'Jewel', total sugar content was twice as much as cultivars, 'Sumor', '99', and '86' . In baked roots total sugar content increased in all cultivars. Horvat *et al.*(1991) noted that in 'Jewel' roots of large size, the amount of total sugars increased with cooking.

CONTENT OF MALTOSE IN COOKED CAMBIUM AND INNER TISSUE OF 'BEAUREGARD' AND 'JEWEL'

The analysis of maltose in sweetpotato roots was based on observations of cooked samples. The results of maltose concentration in sweetpotato roots show that it depends on processing, cultivar, size, and zone, as individual factors or in interactions at different levels (Figure 6). Maltose concentration was not statistically influenced ($p<0.05$) by storage. However the results show that the concentration of maltose varies depending on cultivar, size, and zone.

Maltose concentration was significantly ($p<0.05$) higher in 'Beauregard' than in 'Jewel'. Large roots had significantly higher maltose than small roots in cambium of roots stored for 4 months. The inner tissue had significantly ($p<0.05$) higher maltose than cambium in both large and small roots of 'Beauregard'. In 'Jewel' there was no significant variation between zones of large roots but the zones were significantly different in small roots. Regardless of zone, 'Beauregard' always had more maltose than the corresponding zone in 'Jewel'.

In this research storage did not significantly ($p<0.05$) influence maltose concentration. Several researchers reported changes of maltose with length of storage in experiments conducted at longer storage duration.



F= Four months storage L= Large roots U= Uncooked
T= Three months storage S= Small roots P= Cooked

Figure 6. Concentration (% fresh weight) of maltose (expressed as least square means) of cooked cambium and inner tissue of small and large 'Beauregard' and 'Jewel' roots, stored for three and four months, with a standard error of 0.36.

Some of them reported that the increase of maltose concentration was significant in the first month storage and was reduced afterwards. Walter and Hoover (1986, 1984) reported reduction of maltose in 'Jewel' and 'Centennial' roots stored up to 26 weeks before cooking and processing into patties or french-fry products. After 3 and 4 months in 'Jewel' it decreased from about 3.5 to 3% fresh weight.

Wu *et al.*(1991) observed maltose reduction after one month (10.44%, fresh weight) compared to 3 months (9.77%) storage in large roots of 'Jewel'. In frozen roots there was no change. Picha (1986b) reported a decrease of maltose after 14 weeks storage (7.55 %, fresh weight) compared with 4 weeks storage (8.32%) in 'Jewel' roots baked at 190°C. Maltose also decreased in three other cultivars and increased in two. Deobald *et al.*(1969) referring to maltose content after one and seven days storage, it increased from 9.62% to 20%, dry basis, in raw grind, and decreased from 40.33% to 36.28% in puree of 'Goldrush' roots.

Mandava (1995) reported different results in lye-peeled whole roots of 'Beauregard' and 'Jewel' depending on size and cooking time. Maltose concentration was higher in small size and decreased in large roots while in this study maltose was significantly higher in large roots. Within 'Jewel', small roots had more maltose than large roots during 40 minutes steaming. Within 'Beauregard', small roots had more maltose than large roots during 10 minutes cooking, and then increased or had about the same. In her study, 'Beauregard' had more maltose than 'Jewel' only in large roots during 40 minutes steaming. In this study 'Beauregard' had significantly more maltose than 'Jewel'. There was no significant difference in small roots of both cultivars while the present study found

differences between them. The variation may be due to processing conditions. Woodroof and Atkinson (1944) reported 10- 11% fresh weight of maltose in boiled roots of medium size (correspondent to large size of this study) depending on cooking duration.

Processing was an obvious factor for maltose production in sweetpotato roots. Ground samples were cooked in waterbath during one hour at 70°C. Maltose was detected in a few raw roots, in amounts of 0- 2.6 % fresh weight. It may be a premature conversion due to environmental and/or physiological changes during curing or storage. After cooking the average of maltose was 0-5% fresh weight. In some cooked samples maltose was not detected, particularly in 'Jewel'. This was most likely due to the rapid rise in temperature which inactivated the α-amylase. 'Beauregard', 'Jewel' and/or other cultivars with different lengths of storage, different peeling and cooking methods, temperature, and duration have been evaluated. Maltose content in 'Jewel' roots increased about 18 times in baked roots, representing more than 50% of total sugars produced during baking (Morrison *et al*, 1993).

Sun *et al.* (1993) studied the influence of temperature on maltose content. They found trace amounts of maltose in baked 'Jewel' at 50° C or less. It increased to maximum concentration of 4.3 % fresh weight at 80° C and afterwards decreased. Similar results of maximum maltose at 70° C were obtained by McMardle and Bouwkamp (1986) in steamed and mashed 'Rojo Blanco' cultivar. Losh *et al.* (1981) reported maximum maltose in baking 'Jewel' roots at 230° C. These results suggest that maltose production strongly depend on cooking method and conditions.

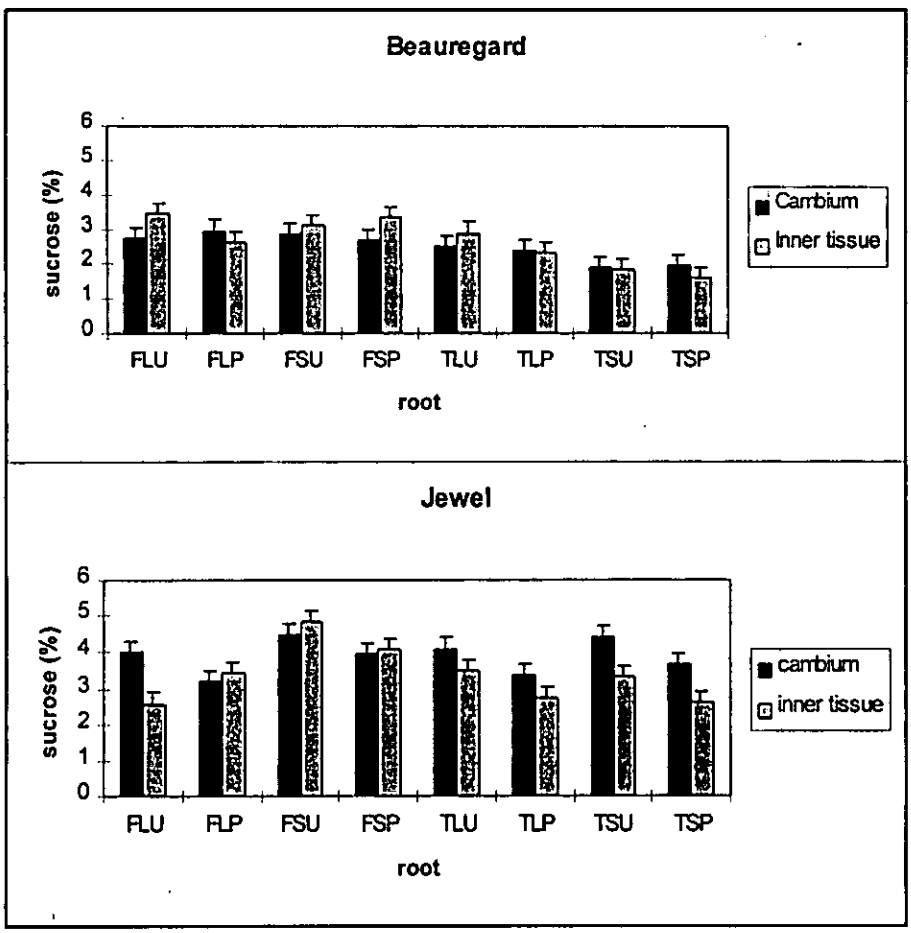
Horvat *et al.* (1991) studied 'Jewel', 'Tainung 57', and 'No.99' cultivars. They found little maltose in raw 'Jewel' roots (0.03 %, fresh weight) but a significant increase

to 3.81% after baking, that was less than 'Tainung 57'(5.3%) and higher than 'No.99' (0.07%). Walter *et al.* (1975) reported maltose production in baked samples of 'Jewel' and five other cultivars. Maltose production was lower in 'Jewel' after 71 days storage than in other cultivars.

Picha (1986b, 1985) reported maltose being the dominant sugar in baked roots of 'Jewel' and three other orange-flesh and two white-flesh cultivars. Maltose was not detected in raw roots. Maltose increased with length of storage and only cooked samples had maltose, at levels of 2- 4.5% fresh weight in roots stored for 0-24 weeks, respectively (Walter and Hoover, 1984).

SUCROSE CONTENT IN TWO ZONES OF 'BEAUREGARD' AND 'JEWEL'

The sucrose concentration in sweetpotato roots ranged from 1.6% fresh weight in cooked inner tissue of small roots of 'Beauregard' stored for 3 months to 4.82% fresh weight in raw inner tissue of small 'Jewel' stored for 4 months (Figure 7). Cultivar, storage, and processing influenced significantly ($p<0.05$) sucrose content. The concentration of sucrose was significantly ($p<0.05$) higher in cambium than in inner tissue of all roots of either cultivar stored for 3 months. It was significantly high in 'Jewel' roots stored for 3 months. Inner tissue of roots stored for 4 months had significantly more than 3 months storage. Small roots with 4 months storage had significantly higher sucrose than roots stored for three months. In each zone 'Jewel' had more sucrose than 'Beauregard', either in cambium or inner tissue. Cooked 'Jewel' had significantly ($p<0.05$) more sucrose than cooked 'Beauregard'. In 'Jewel' raw roots had significantly higher sucrose than cooked roots.



F= Four months storage L= Large roots U= Uncooked
T= Three months storage S= Small roots P= Cooked

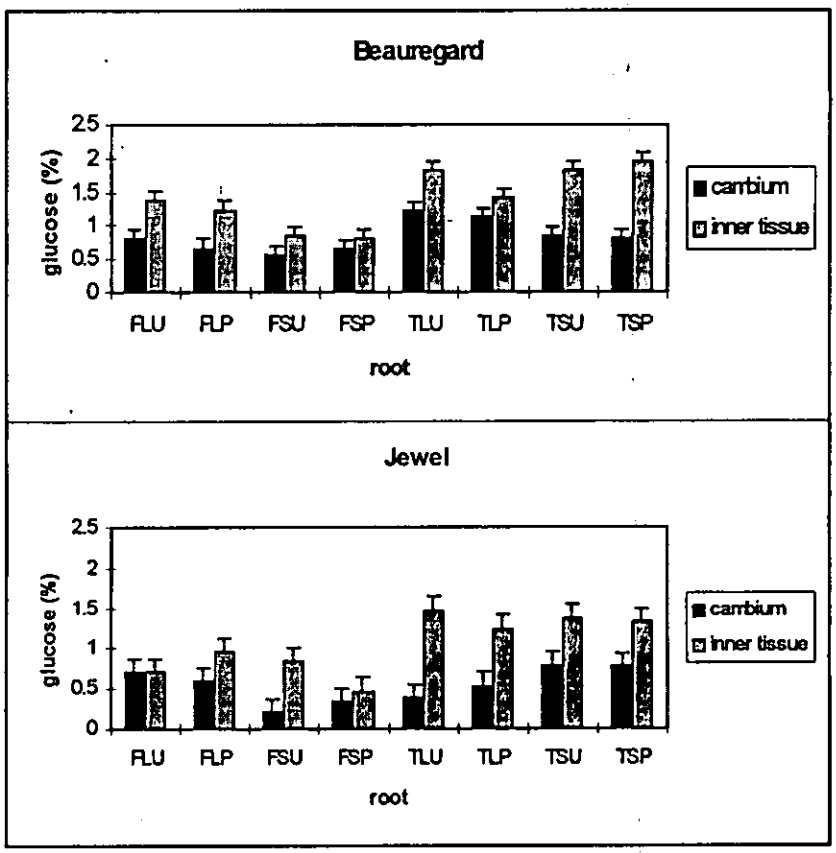
Figure 7. Concentration (% fresh weight) of sucrose (expressed as least square means) of raw and cooked cambium and inner tissue of small and large 'Beauregard' and 'Jewel' roots, stored for three and four months, with a standard error of 0.30.

Storage and cooking was analyzed by other researchers as factors that may influence concentration of sucrose and other sugars. Some variations were observed, but in general an increase of sucrose was observed during curing and storage at levels depending on storage conditions. Previous studies reported that 'Jewel' contained more sucrose than 'Beauregard'. Mandava (1995) found about 16.9%, fresh weight, sucrose in all roots of 'Jewel' and 15.6% in 'Beauregard'. Wilson *et al* (1994) results also show that 'Jewel' had 14%, fresh weight, sucrose and 'Beauregard' about 10% in roots stored for eight weeks at 15°C.

CONCENTRATION OF GLUCOSE AND FRUCTOSE IN RAW AND COOKED CAMBIUM AND INNER TISSUE OF SWEETPOTATO ROOTS

The results of this study show that glucose ranged from 0.2% fresh weight in raw cambium of small 'Jewel' roots stored for 4 months to 1.97% in cooked inner tissue of small 'Beauregard' stored for 3 months (Figure 8). Glucose was significantly ($p<0.05$) higher in 'Beauregard' than in 'Jewel'roots in the inner tissue of large roots stored for 4 months and of small roots stored for 3 months, and in cambium of small roots stored for 3 months in both cultivars.

Within 'Beauregard, there were variations among roots. Glucose was significantly ($p<0.05$) higher in inner tissue than in cambium of large roots stored for 3 and 4 months and of small roots stored for 3 months. Large roots had significantly more glucose than small roots in inner tissue of roots stored for 4 months. Storage influenced significantly the glucose content in the cambium of large roots and in inner tissue of small roots, in which, glucose was significantly ($p<0.05$) higher in roots stored for 3 than for 4 months.



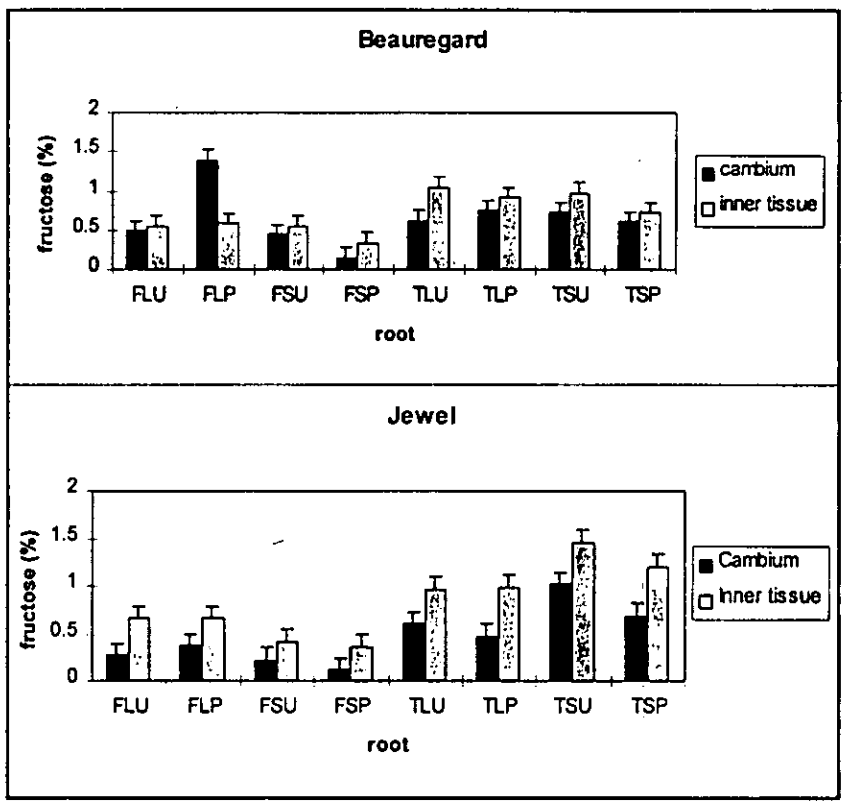
F= Four months storage L= Large roots U= Uncooked
T= Three months storage S= Small roots P= Cooked

Figure 8. Concentration (% fresh weight) of glucose (expressed as least square means) in raw and cooked cambium and inner tissue of small and large 'Beauregard' and 'Jewel' roots, stored for three and four months, with a standard error of 0.17.

In 'Jewel' roots, there were also variations among roots. The inner tissue had significantly ($p<0.05$) higher glucose than cambium in small roots stored for 4 months, and in large and small roots stored for 3 months. Size did not affect significantly the glucose content in 'Jewel' roots. Storage was an influenceable factor, roots stored for 3 months were significantly ($p<0.05$) higher than 4 months storage in inner tissue of large and small roots, and in cambium of small roots. In summary, glucose concentration depended on interactions among cultivar, storage, size, zone, and processing. In general, this sugar was higher in 'Beauregard' than 'Jewel', roots stored for 3 months had more glucose than 4 months storage, large roots had higher glucose than small roots, inner tissue was higher than cambium and raw roots had more glucose than cooked roots. Previous studies referred to small changes in glucose concentrations.

The concentration of fructose was between 0.2% in raw cambium of small 'Jewel' stored for 4 months to 1.97% fresh weight in cooked inner tissue of small 'Beauregard' stored for 3 months (Figure 9). Cultivar, length of storage, root size, root zone, and processing influenced fructose concentrations in sweetpotato roots. Cultivars had variations in fructose concentration, 'Beauregard' was significantly higher than 'Jewel' in cambium of large roots stored for 4 months, particularly in cooked roots. It was lower in raw roots of small size stored for 3 months particularly in the inner tissue.

Within 'Beauregard' the variations were very dependent on other factors, being significant in some combinations. Storage was a significant factor in the following combinations: roots stored for 3 months had significantly more fructose than 4 months storage roots in inner tissue of large and small roots, and in cambium of small roots;



F= Four months storage L= Large roots U= Uncooked
T= Three months storage S= Small roots P= Cooked

Figure 9. Concentration (% fresh weight) of fructose (expressed as least square means) in raw and cooked cambium and inner tissue of small and large 'Beauregard' and 'Jewel' roots, stored for three and four months, with a standard error of 0.13.

fructose was also in higher concentrations in 3 months than 4 months storage in raw large and small roots, especially in cooked small roots. Cambium had significantly more fructose than inner tissue in large roots stored for 4 months. It was less in cambium than in inner tissue in large roots stored for 3 months. Large roots had significantly more fructose than small roots in cambium, particularly in cooked large roots stored for 4 months. Raw 'Beauregard' had higher sucrose than 'cooked large roots stored for 4 months.

In 'Jewel' cultivar the variations also depended on the combinations of various factors. Fructose content was significantly higher in roots stored for 3 months than for 4 months in inner tissue of large and small roots, and in cambium of small roots; in raw small and raw large roots, and in cooked small roots of 'Jewel'. The raw small roots stored for 3 months had more sucrose than cooked roots. Fructose was also significantly higher in inner tissue than cambium of large roots stored for 4 months and in large and small roots stored for 3 months. Fructose was significantly higher in cambium and in inner tissue of small than in large roots stored for 3 months. In small raw roots it was higher than in large roots stored for 3 months. Large cooked roots had more fructose than small roots stored for 4 months.

These significantly different ($p<0.05$) combinations show that there is no direct relationship among any of the factors for fructose concentration. However, it can be considered, in general, that 3 months stored roots had more fructose than 4 months stored roots. In 'Beauregard' large roots had more fructose than small roots but in 'Jewel' small roots had more than large roots. Cooked roots had significantly more fructose than raw roots only in 'Beauregard'. In 'Jewel' raw roots had significantly more fructose than cooked

roots. Cambium with higher fructose than inner tissue was only observed in 'Beauregard'. The inner tissue was higher than cambium in both 'Beauregard' and 'Jewel'.

SUMMARY AND CONCLUSIONS

SUMMARY

The study investigated the influence of cultivar, length of storage, root size, and processing on the concentration of α-amylase, alcohol insoluble solids (AIS), and soluble sugars (total sugars, maltose, sucrose, fructose, and glucose) in two zones of sweetpotato roots. The two zones examined were the cambium and the inner tissue. The roots of 'Beauregard' and 'Jewel' were categorized according to size with large roots being 6.35-8.89 cm diameter and small roots being 1.9-3.8 cm diameter. After curing for 10 days at 30 °C and 90% relative humidity, the roots were stored for three and four months at 15 °C and 85% relative humidity.

Four roots were randomly selected from each group of roots divided by cultivar, length of storage and size. Each root was further subdivided into two zones. Alpha-amylase was determined only in raw samples. Each sample was subdivided into two subsamples. Each of these was analyzed in duplicate by using a commercial substrate, amylopectin azure. The enzyme activity was quantified by reading the absorbance of the filtrate in a spectrophotometer. Determination of AIS and sugars were done in duplicate for each zone, raw and cooked. AIS was measured by difference of fresh weight and dry matter after sugar extraction by ethanol. Sugars were quantified by high-performance-liquid-chromatograph (HPLC). Data were statistically analyzed using Analysis of Variance (ANOVA), by SAS PROC mixed procedure.

Sweetpotato roots are processed after curing and/or storage throughout the year, but canning is done preferably in fresh roots or within 2-3 months after harvest. 'Beauregard'

and 'Jewel' are sweetpotato cultivars commonly used by industry for canning, patties, baby food, frozen products, and other products. Small roots are preferred by the canning industry and medium roots are often directed to fresh market.

The results showed a significant interaction among cultivar, length of storage, root size, root zone, and processing on composition of the roots. The significance was not uniform for the various combinations, giving a non-linear relationship between or among factors and variables. There was a general lack of observation consistency even within one type of sweetpotato.

The analysis of individual factors (cultivar, storage, size, zone, and processing) demonstrated a variation within and among them. Applying the least square means (lsmeans) to assess the various factors, there was a substantial and statistically significant difference in α-amylase activity, AIS, total sugars, maltose, sucrose, fructose, and glucose concentrations of raw and cooked 'Beauregard' and 'Jewel'.

Raw 'Beauregard' was significantly ($p<0.05$) higher than 'Jewel' in α-amylase activity. Raw and cooked 'Beauregard' was also higher in maltose and glucose. 'Beauregard' contained significantly ($p<0.05$) less sucrose than 'Jewel'.

Alpha-amylase activity and glucose content were significantly higher ($p<0.05$) in cambium than in inner tissue of the overall roots. However, it was significantly lower in maltose and fructose. Comparing roots by zone, there was no significant difference ($p<0.05$) between cambium and inner tissue in AIS, sucrose, and total sugar contents.

Cooked roots were significantly higher ($p<0.05$) than raw roots in AIS and total sugar. Cooked roots were significantly lower ($p<0.05$) in sucrose. There was no significant difference in fructose and glucose between raw and cooked roots.

Roots stored for four months had statistically ($p<0.05$) higher glucose and fructose than roots stored for three months. They were lower in α-amylase and sucrose. There were significant differences between storage times in total sugars, maltose, and AIS.

Large roots were significantly ($p<0.05$) higher than small roots in total sugar, maltose, and significantly less in α-amylase. AIS, sucrose, fructose and glucose were not significantly different comparing large and small roots in general.

Storage in combination with other factors influenced α-amylase content and AIS concentration but did not affect total sugars.

Size is an important grading parameter for roots selection and helps standardize factory equipment settings to reduce losses during peeling and trimming losses in sweetpotato processing plants. Size seems to influence the rate of heat penetration, it is lower in large roots, consequently affecting the composition of zones of roots, cambium and inner tissue. In this study the root selection was based only on root diameter regardless of different lengths and shapes. The roots appear to differ in cambium depth and texture for different shapes and lengths (some were almost round and others were long roots). These observations suggest that length and shape besides diameter may affect the physiological and rheological/organoleptic properties of roots.

Cooking obviously affected all variables at different levels, with significant differences between raw and cooked samples. Glucose appears to be the sugar with least

variation caused by cooking, it was significantly different in raw and cooked roots. The relationship between cooking and other factors were not linear, depended on which factors were in the interactions.

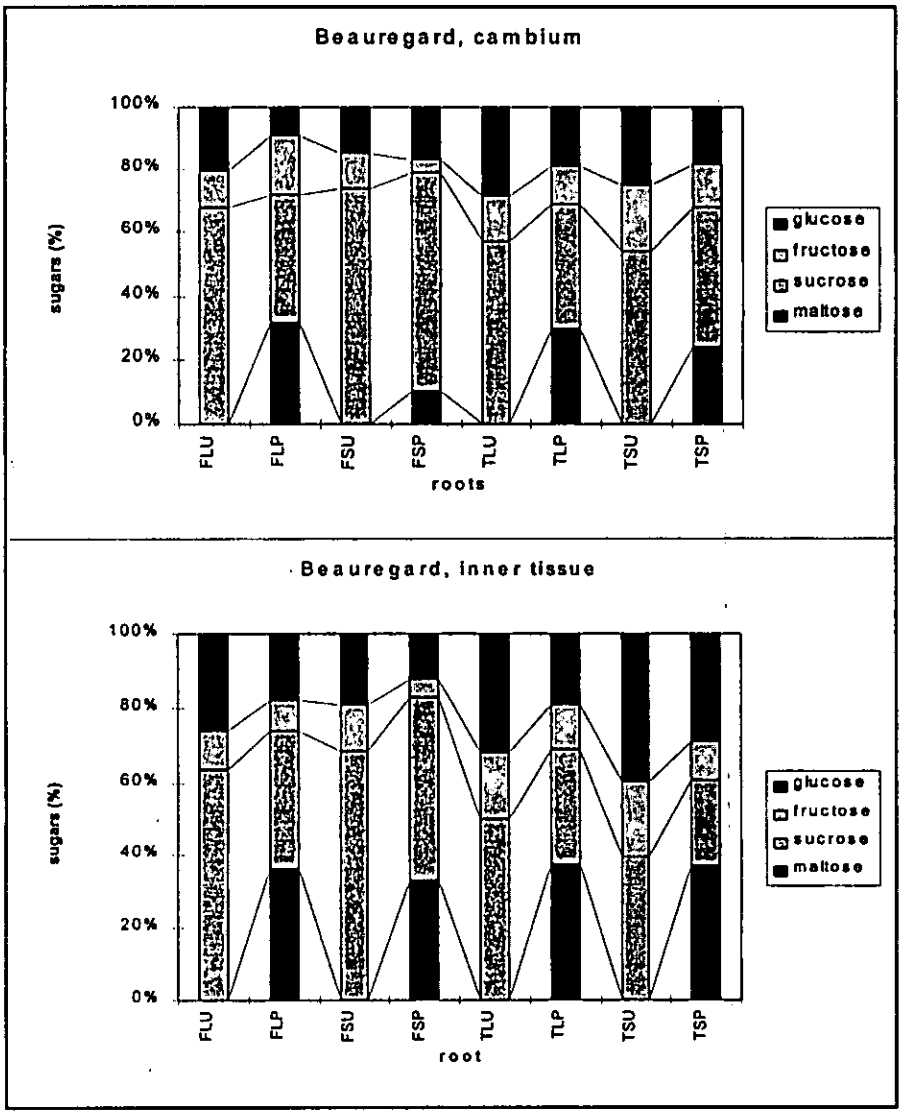
The enzyme activity in raw roots was influenced by cultivar, storage, size, and zone. Its concentration varied from 0.48 APA units (lsmeans) in the inner tissue of raw small 'Jewel' roots stored for four months to 2.71 APA units (lsmeans) in 'Beauregard' roots with the same characteristics (inner zone of raw small roots stored for four months). In any case 'Beauregard' had more enzyme than 'Jewel', roots stored for four months had more than roots stored for three months, small roots had more than large roots. The concentration by zone depended on cultivar, there was no significant difference between zones of 'Jewel'. In 'Beauregard' there was more α-amylase in cambium than in inner tissue. Higher concentration in cambium may be due to the age of cells, considered younger than the cells from inner tissue. The analytical method used for α-amylase was previously determined in 'Jewel' and other cultivars but not in 'Beauregard'. The results showed a similar trend in terms of increase/ decrease of enzyme concentration by cultivar and storage.

Alcohol insoluble solids (AIS) concentration ranged from 11.7% in the inner tissue of cooked small 'Beauregard' stored for three months to 21.01% also in the inner tissue of small 'Beauregard' in raw roots stored for four months. Cooking significantly reduced AIS. Its concentration was higher in small roots, in cambium of 'Beauregard' and in inner tissue of 'Jewel'. It is equivalent to where the enzyme is concentrated, but it should be the reverse by the fact that AIS is reduced by enzyme activity. It suggests that other factors and other root constituents may influence the reaction enzyme-starch for sugar production.

Total sugars include maltose, sucrose, fructose and glucose (Figures 10 and 11). The concentration ranged from 3.66% in cambium of raw small 'Beauregard' roots stored for three months to 7.66% in cambium of cooked large 'Beauregard' roots stored for four months. As mentioned before, total sugars were not affected by storage. Heating increased total sugars, with significant difference in large roots and inner zone of 'Beauregard' due to the increase of maltose.

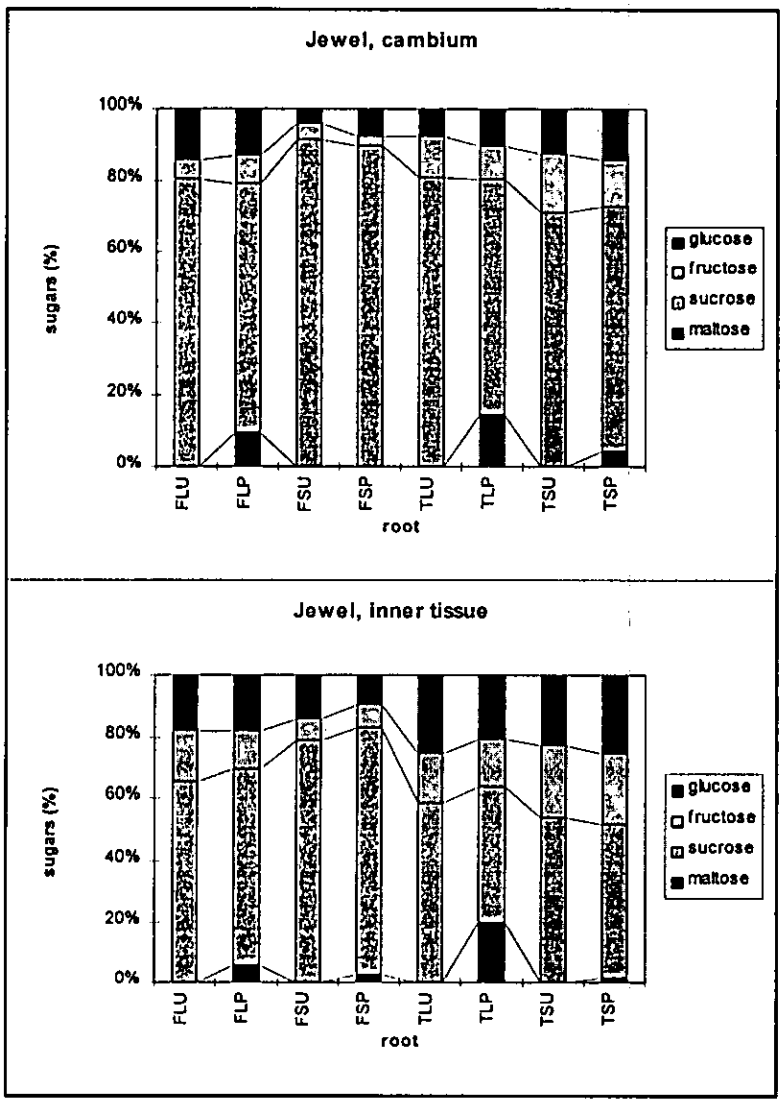
Total sugars concentration was not directly related to α-amylase. Total sugars were greater in large than in small roots and more in inner tissue (same as maltose in 'Beauregard') while the enzyme is concentrated in cambium and in small roots. Storage increased enzyme concentration but did not affect the concentration of total sugars. This indicates that other factors may affect total sugars concentration in both raw and cooked sweetpotato roots. Total sugars were inversely related to AIS in cooked samples. Cooking reduced AIS and increased total sugars.

Maltose was detected mainly in cooked samples. In a few raw samples it was present, possibly due to uncontrolled variation of temperature or other environmental factors during curing, storage, pre-processing that cause starch conversion. Half of the samples were in concentrations below 1%. The variation did not follow any pattern. Low values were found in both cultivars, length of storage , root size or root zone. In any case, 'Beauregard' had more maltose than 'Jewel' and large roots had more than small roots.



F= Four months storage L= Large roots U= Uncooked
T= Three months storage S= Small roots P= Cooked

Figure 10. Concentration (%) of maltose, sucrose, fructose and glucose in two zones of raw and cooked, small and large 'Beauregard' roots, stored for three and four months.



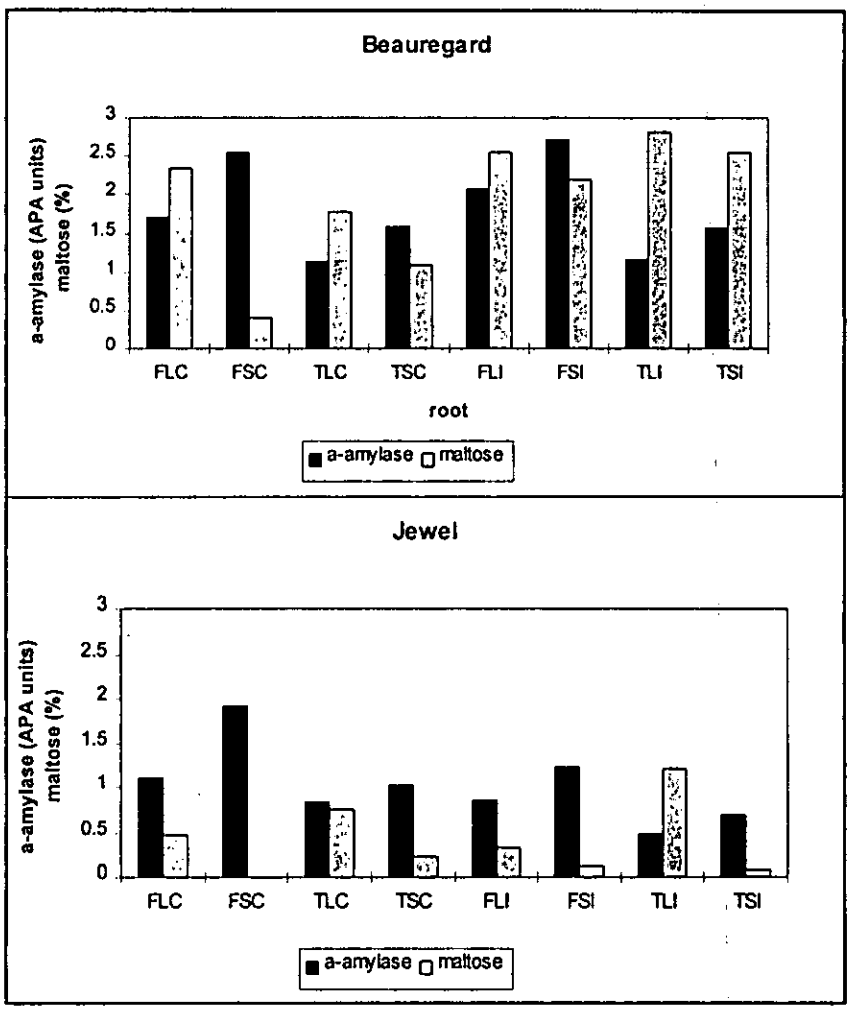
F= Four months storage L= Large roots U= Uncooked
T= Three months storage S= Small roots P= Cooked

Figure 11. Concentration (%) of maltose, sucrose, fructose and glucose in two zones of raw and cooked, small and large 'Jewel' roots, stored for three and four months.

There was no direct linear relationship between α-amylase and maltose concentration but both were in higher concentration in 'Beauregard' than in 'Jewel' (Figure 12). This may be interpreted as a relationship between these two variables, in which more α-amylase promoted maltose production. Alpha-amylase was higher in cambium while maltose was higher in inner tissue of 'Beauregard'. The enzyme was concentrated in small roots while maltose was in large roots. The ratio of high enzyme activity: low maltose production in small roots and the reverse in large roots show that other factors and chemical composition of roots influenced the enzymatic activity and production of sugars.

Sucrose levels ranged between 1.6 to 4.82%. 'Jewel' had more sucrose than 'Beauregard' and there were no significant variations between large and small roots. Storage influenced sucrose depending on the size of the roots, being higher in small roots stored for four months. Differences in zones depended on cultivar and storage. Processing increased significantly sucrose content in 'Jewel'. Sucrose was also higher in 'Beauregard'. Sucrose was the main sugar in raw roots. Its concentration was not reduced by processing but in cooked roots it became the second most prevalent sugar due to the significant increase of maltose.

Glucose concentration depended on interactions among cultivar, storage, size, zone, and processing. In general, this sugar was higher in 'Beauregard' than in 'Jewel'. Roots stored for three months had more glucose than those with four months storage. Large roots had higher glucose than small roots. Inner tissue was higher than cambium and raw roots had more glucose than cooked roots.



F= Four months storage L= Large roots
T= Three months storage S= Small roots

Figure 12. Relationship between alpha-amylase activity in raw and maltose concentration (%) in cooked cambium and inner tissue of small and large, 'Beauregard' and 'Jewel' roots, stored for three and four months.

The concentration of fructose was between 0.2% and 1.97% fresh weight. Cultivar, length of storage, root size, root zone, and processing influenced fructose concentrations in sweetpotato roots depending on combinations among them at different levels. There was no recognizable pattern of fructose concentration by type of roots and different levels of combinations

CONCLUSIONS

This study provided more information concerning the 'Beauregard' cultivar, for which limited information is available. Most of the results with 'Jewel' roots confirmed previous findings but some are different. The significant interactions that occurred in each variable did not follow a clear pattern which makes it difficult to draw conclusions. This study should be helpful to the sweetpotato industry because it provides information on 'Beauregard', a relatively new cultivar, released in 1987 by Louisiana Agricultural Experiment Station of Louisiana State University.

From this study 'Beauregard' appears to be the more desirable cultivar for processing of sweet tasting products. The large roots of 'Beauregard' have more sugars. By the fact that sugars are concentrated in the inner tissue, peeling is not a problem in 'Beauregard. 'Jewel' cultivar requires more studies on composition of zones. The results of the present study indicate that α-amylase is concentrated in cambium of 'Jewel'. It indicates that peeling may remove a significant amount of enzyme which may influence the quality of end products.

The results also suggest more studies on peeling methods for different cultivars and for different types of products. Such studies might provide information on the influence of

peeling on sweetpotato composition by zone and rheological properties of their products before and after peeling. Peeling losses, defined mainly as the amount of material that is removed by peeling, might represent a parameter not simply for weight, but also for nutritional and functional values whose losses may be significant. The excessive removal of cambium by peeling may represent removal of the tissue where enzymes are concentrated. It may reduce starch conversion and consequently cause changes in chemical and rheological characteristics of the end product.

Small roots are the preference for the canning industry. Large roots are not preferred by industry nor by fresh market consumers. The results demonstrate that large roots may give better quality puree products than small roots.

The results show how substrate and reaction conditions influence the results. Other enzymes such as β- amylase and phosphorylase may also influence the mechanism of enzyme-carbohydrate interaction. They may be the reason for such chemical changes in the roots as: why AIS content was higher in the same zone where α-amylase was in highest concentration; why in 'Jewel' heating caused a reduction of total sugars instead increasing as expected.

The commercial substrate Amylopectin Azure in the method of α-amylase determination gave very low values, which may have produced variable results. Other substrates are recommended to be tested using the same analytical protocol.

RECOMMENDATIONS

Findings of this study may be a contribution to sweetpotato research. Based on this study, large roots of 'Beauregard' would be recommended if sweetness is desirable in a

heat processed product. Further studies are recommended on (1) the influence of cultivar and size in raw and cooked zones of roots harvested on different years; (2) the composition of root zones before and after peeling using different peeling methods and the characteristics of the end products; (3) the influence of other enzymes such as β- amylase and phosphorylase on the enzyme-carbohydrates mechanism in each zone of sweetpotato roots; and (4) the reliability of analytical substrates in the enzyme analysis.

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Appendix 1. Alpha- amylase activity (APA units/ml juice) in raw cambium and inner tissue of large and small roots of 'Beauregard' and 'Jewel' cultivars stored for three and four months.

Tissue Location	Four months storage		Three months storage	
	Large Roots	Small Roots	Large Roots	Small Roots
BEAUREGARD				
Cambium	1.71* [a]	2.56[d]	1.13[b]	1.59[a]
Inner tissue	2.07[a]	2.71[d]	1.16[b]	1.56[a]
JEWEL				
Cambium	1.10[b]	1.92[e]	0.83[c]	1.03[b]
Inner tissue	0.85[c]	1.23[b]	0.48[f]	0.69[c]

* Least square means with standard error = 0.21

[a,f] Significantly different at $p<0.05$

Appendix 2. Concentration (% fresh weight) of alcohol insoluble solids (AIS) in raw and cooked cambium and inner tissue of large and small roots of 'Beauregard' and 'Jewel' cultivars stored for three and four months.

Tissue Location	Four months storage				Three months storage			
	Large Roots		Small Roots		Large Roots		Small Roots	
	Unprocessed	Processed	Unprocessed	Processed	Unprocessed	Processed	Unprocessed	Processed
BEAUREGARD								
Cambium	17.80*[a]	14.53[g]	20.25[i]	16.38[b]	17.85[a]	14.41[g]	18.24[c]	14.38[g]
Inner tissue	17.71[a]	13.54[h]	21.01[i]	17.13[f]	16.70[b]	13.03[h]	16.56[b]	11.70[j]
JEWEL								
Cambium	15.03[c]	14.85[g]	16.60[b]	15.00[c]	19.05[d]	18.05[e]	16.91[b]	13.98[j]
Inner tissue	16.58[b]	16.25[b]	17.91[f]	16.18[b]	18.41[e]	16.13[b]	15.90[h]	14.50[g]

* Least square means with standard error = 0.99

[a-j] Significantly different at $p<0.05$

Appendix 3. Concentration (% fresh weight) of total sugars in raw and cooked cambium and inner tissue of large and small roots of 'Beauregard' and 'Jewel' cultivars stored for three and four months.

Tissue Location	Four months storage				Three months storage			
	Large Roots		Small Roots		Large Roots		Small Roots	
	Unprocessed	Processed	Unprocessed	Processed	Unprocessed	Processed	Unprocessed	Processed
BEAUREGARD								
Cambium	4.06*[a]	7.66[f]	4.20[a]	3.90[a]	4.61[d]	6.05[g]	3.66[a]	4.47[a,d]
Inner tissue	5.53[b]	7.01[c]	4.63[d]	6.64[c]	5.09[b]	7.47[f]	4.72[d]	7.62[f]
JEWEL								
Cambium	4.98[c]	4.66[d]	5.16[b]	4.40[a]	5.40[b]	5.36[b]	6.24[g]	5.35[b]
Inner tissue	5.10[c]	5.36[b]	6.67[c]	5.43[b]	6.03[b]	6.15[g]	6.49[c]	5.25[b]

* Least square means with standard error = 0.51

[a,g] Significantly different at $p<0.05$

Appendix 4. Concentration (% fresh weight) of maltose in cooked cambium and inner tissue of large and small roots of 'Beauregard' and 'Jewel' cultivars stored for three and four months.

Tissue Location	Four months storage		Three months storage	
	Large Roots	Small Roots	Large Roots	Small Roots
BEAUREGARD				
Cambium	2.34* [a]	0.40[b]	1.78[d]	1.08[f]
Inner tissue	2.54[a]	2.20[a]	2.55[a]	2.55[a]
JEWEL				
Cambium	0.46[b]	0.00[h]	0.76[e]	0.23[g]
Inner tissue	0.32[b]	0.13[e]	1.21[f]	0.08[e]

* Least square means with standard error = 0.36

[a,h] Significantly different at $p<0.05$

Appendix 5. Concentration (% fresh weight) of sucrose in raw and cooked cambium and inner tissue of large and small roots of 'Beauregard' and 'Jewel' cultivars stored for three and four months.

Tissue Location	Four months storage				Three months storage			
	Large Roots		Small Roots		Large Roots		Small Roots	
	Unprocessed	Processed	Unprocessed	Processed	Unprocessed	Processed	Unprocessed	Processed
BEAUREGARD								
Cambium	2.75*[a]	2.94[a]	2.84[a]	2.70[a]	2.48[f]	2.37[f]	1.88[g]	1.96[g]
Inner tissue	3.42[b]	2.63[a]	3.09[b]	3.31[b]	2.88[a]	2.32[f]	1.85[g]	1.60[g]
JEWEL								
Cambium	4.00[c]	3.22[b]	4.50[d]	3.95[c]	4.10[c]	3.39[b]	4.44[d]	3.66[b]
Inner tissue	2.59[a]	3.42[b]	4.82[e]	4.05[c]	3.48[b]	2.72[a]	3.33[b]	2.64[a]

* Least square means with standard error = 0.30

[a,g] Significantly different at $p<0.05$

Appendix 6. Concentration (% fresh weight) of fructose in raw and cooked cambium and inner tissue of large and small roots of 'Beauregard' and 'Jewel' cultivars stored for three and four months.

Tissue Location	Four months storage				Three months storage			
	Large Roots		Small Roots		Large Roots		Small Roots	
	Unprocessed	Processed	Unprocessed	Processed	Unprocessed	Processed	Unprocessed	Processed
BEAUREGARD								
Cambium	0.49*[b]	1.40[f]	0.44[b]	0.15[a]	0.62[e]	0.75[g]	0.72[g]	0.61[e]
Inner tissue	0.55[d]	0.58[d]	0.55[d]	0.33[c]	1.04[f]	0.90[f]	0.97[f]	0.72[g]
JEWEL								
Cambium	0.27[a]	0.37[c]	0.22[a]	0.11[a]	0.60[e]	0.47[b]	1.01[f]	0.69[e]
Inner tissue	0.66[e]	0.66[e]	0.40[b]	0.36[c]	0.96[f]	0.98[f]	1.45[f]	1.20[f]

* Least square means with standard error = 0.13

[a,f] Significantly different at $p<0.05$

Appendix 7. Concentration (% fresh weight) of glucose in raw and cooked cambium and inner tissue of large and small roots of 'Beauregard' and 'Jewel' cultivars stored for three and four months.

Tissue Location	Four months storage				Three months storage			
	Large Roots		Small Roots		Large Roots		Small Roots	
	Unprocessed	Processed	Unprocessed	Processed	Unprocessed	Processed	Unprocessed	Processed
BEAUREGARD								
Cambium	0.82*[a]	0.68[c]	0.56[c]	0.66[c]	1.24[b]	1.14[b]	0.86[a]	0.82[a]
Inner tissue	1.39[b]	1.25[b]	0.86[a]	0.81[a]	1.82[f]	1.42[e]	1.84[f]	1.97[f]
JEWEL								
Cambium	0.71[a]	0.59[c]	0.20[d]	0.34[d]	0.38[d]	0.53[c]	0.79[a]	0.77[a]
Inner tissue	0.70[a]	0.96[a]	0.85[a]	0.47[c]	1.47[e]	1.25[b]	1.38[b]	1.33[b]

* Least square means with standard error = 0.17

[a,f] Significantly different at $p<0.05$

VITA

Lara da Silva Carrilho was born in Beira, Mozambique, on July 12, 1957. She received her bachelor of science degree in Agricultural Engineering from Universidade Eduardo Mondlane in January 1978. She worked for the Ministry of Agriculture from 1978 to 1986 as an Agronomist, Project Manager and Provincial Director. She also briefly worked for the Ministry of Education as a producer of Adult Education training manuals. From 1987 to 1991 she worked for the Food Industry as a Food Technologist and Technical Director of a parastatal holding enterprise. She attended Food Technology and Management, and Training for Trainers of Women Entrepreneurs courses at the RVB Institute of Management, Delft, the Netherlands. In 1992 she joined the School of Agriculture and Forestry Engineering, Universidade Eduardo Mondlane, as lecturer in Food Technology. She also served as Deputy Dean for Academic Affairs.

Lara has, from time to time, evaluated rural development projects and training programs for women and represented her country at various food industry related international conferences. In the execution of such duties, she has visited several African and European countries, and Brazil. She is a founder-member of the Mozambican Association for Women Executives and Entrepreneurs, and is a member of the Institute of Food Technologists (IFT). She entered Louisiana State University in 1994 and is currently a candidate for the degree of Master of Science in Food Science.