

# Ascorbic Acid, Thiamin, Riboflavin, and Vitamin B<sub>6</sub> Contents Vary between Sweetpotato Tissue Types

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**Abstract.** Sweetpotato is considered a good source of ascorbic acid (vitamin C) and certain B vitamins. These water-soluble vitamins (WSV) play essential roles in sustaining human health. Besides the root, sweetpotato vegetative tissues are also edible and considered high in nutritional value. Despite the availability of general reference values for sweetpotato WSV content in the root and leaves, little is known about the distribution of these vitamins in specific sweetpotato root and vegetative tissues. The objective of this study was to determine the ascorbic acid (AA), thiamin (B<sub>1</sub>), riboflavin (B<sub>2</sub>), and vitamin B<sub>6</sub> content in a range of foliar tissues including buds, vines, young petioles, young leaves, mature petioles, and mature leaves and root tissues including the skin, cortex, and pith tissue at the proximal, distal, and center regions of the root. Among foliar tissues of 'Beauregard' sweetpotatoes, the AA content was highest in young leaves (108 to 139 mg/100 g fresh weight) and lowest in mature petioles (7.2 to 13.9 mg). No thiamin was detected in foliar tissue, whereas mature leaves contained the highest riboflavin and vitamin B<sub>6</sub> content (0.22 to 0.43 mg and 0.52 to 0.58 mg, respectively). In root tissues of 'Beauregard' and 'LA 07-146' sweetpotatoes, the AA content was lower in the skin (1.9 to 5.6 mg and 2.54 to 3.82 mg, respectively). The AA content in the cortex and pith tissue at the proximal, distal, and center of the root was generally similar. The thiamin content was variable among root tissues, whereas the skin contained the highest riboflavin content and the lowest vitamin B<sub>6</sub> content across root tissues of both cultivars. The results of this study confirmed earlier reports suggesting that sweetpotato leaves can be a good source of multiple WSV in the human diet.

Water-soluble vitamins, including AA and B vitamins, are essential compounds for adequate functioning of the human body. They play important roles as coenzymes in a wide variety of metabolic reactions that sustain life (Kawasaki and Egi, 2000; Nielsen, 2000; Padayatty et al., 2003; Ubbink, 2000). AA also has antioxidant properties that may protect the human body against reactive oxygen species (Padayatty et al., 2003). Sweetpotato is considered a good source of AA and a moderate source of certain B vitamins in human diets. Besides the root, other sweetpotato plant tissues including young leaves and petioles are edible and high in nutritional value (Johnson and Pace, 2010). Sweetpotato foliar tissues are predominantly consumed in African and Asian countries, functioning as a source of protein, essential amino acids, antioxidants, vitamins, minerals, and dietary fiber (Johnson and Pace, 2010). Sweetpotato foliar tissues have shown significantly higher contents of certain WSV compared with roots (Ishida et al., 2000). Despite the availability of general reference values for sweetpotato WSV content in root

pith and leaves, little is known on the distribution of these vitamins in other sweetpotato root and foliar tissues.

Limited research has been conducted on the WSV content of different sweetpotato root tissues. An earlier study reported no gradient in thiamin and riboflavin contents from proximal to distal ends of the root. However, thiamin was found more concentrated at 3 mm below the skin compared with the center pith area (Bradbury and Singh, 1986). It is unknown whether other sweetpotato root tissues differ in their WSV content. The objective of this study was to determine the ascorbic acid, thiamin, riboflavin, and vitamin B<sub>6</sub> content in a wide range of edible tissues of 'Beauregard' and 'LA 07-146' sweetpotatoes, two important commercial cultivars in Louisiana.

## Materials and Methods

*Tissue origin and sampling procedure.* Sweetpotato tissues were sampled on 28 Oct. 2012 from a 'Beauregard' sweetpotato plot at the Horticulture Hill Farm Teaching Facility at Louisiana State University, Baton Rouge, LA, and immediately processed for WSV analysis. Sweetpotato tissue types included mature leaves (the tenth fully expanded leaf from the apical meristem),

mature petioles (from sampled mature leaves), young leaves (most recent fully expanded leaf from the apical meristem), young petioles (from sampled young leaves), buds (3 cm from the apical meristem), vine sections (15 cm from the apical meristem), and root tissue (central pith). All tissues were then frozen with liquid nitrogen and finely crushed with a mortar and pestle for WSV extraction and analysis. The experiment was repeated (second experiment) with tissue samples collected on 2 Sept. 2013 from a 'Beauregard' sweetpotato plot at the Louisiana State University (LSU) AgCenter Botanic Gardens, Baton Rouge, LA. For AA, thiamin, and riboflavin analysis, a total of six and five replicates (individual plants) were randomly sampled throughout the fields in the first experiment and second experiment, respectively. For vitamin B<sub>6</sub>, a total of four replicates was used in the first experiment. Vitamin B<sub>6</sub> was not analyzed in the second experiment.

A third experiment was conducted to study WSV content among different sweetpotato root tissues. Sweetpotato root material was collected from the LSU AgCenter Sweetpotato Research Station in Chase, LA. Roots from cultivars Beauregard and LA 07-146 were harvested on 24 Aug. 2012, cured at 29 °C for 6 d, and stored at 14 °C and 85% relative humidity for 5 months before sampling for WSV analyses. Tissues sampled included skins, cortex, pith at the proximal end, pith at the distal end, and pith at the central region of the root (Fig. 1). Skin samples were collected by gently rubbing the sweetpotato root surface with a knife. The cortex tissue was sampled by careful tissue excision with a knife from roots that the skin had previously been removed. To sample pith tissue, the root was peeled (skin and cortex tissue were removed), and a root piece from the indicated pith locations was obtained with a knife. The pith pieces were then finely chopped into smaller pieces. All root tissues were then frozen with liquid nitrogen and finely crushed with a mortar and pestle. A replicate in each tissue type was representative of an individual root. A total of six roots/replications were sampled for all tissues.

*Vitamin extraction and analysis procedures.* All vitamin extraction procedures were conducted using amber vials to prevent photo-degradation of the WSV analytes. The total AA extraction methodology was adapted from Chebroly et al. (2012). Depending on tissue type, 1 g of sweetpotato skins or 3 g of other tissues were placed in an amber vial, and 9 mL of 3% (w/v) meta-phosphoric acid was added. The tissue was homogenized at 3000 rpm for 30 s with a 1-cm diameter VirtiShear homogenizer (The Virtis Co., Gardiner, NY), and then the content was transferred to a 15-mL test tube. The sample was centrifuged at 12,857 × g for 10 min. Approximately 3 mL of the supernatant was carefully filtered through a Phenex 25 mm, 0.45-µm nylon membrane syringe filter, (Phenomenex Inc., Torrance, CA). Then, 0.5 mL of the filtered sample was transferred to an amber 8 × 40 mm (1 mL) high-performance liquid chromatography

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(HPLC) vial and then mixed with 0.5 mL of 5 mmol/L of tris(2carboxyethyl)phosphine hydrochloride. The sample was manually agitated for 15 s and then allowed to remain at room temperature (21 °C) for 30 min for complete reduction of dehydroascorbic acid to AA. The sample was then analyzed for total AA content by injecting 5  $\mu$ L of the sample in an HPLC system (Waters Corp., Milford, MA) consisting of a Model W600 pump, a 717 Plus autosampler, and a 2487 ultraviolet detector. The separation was achieved with a reverse phase C18 GraceSmart column (150 mm  $\times$  4.6 mm, 3- $\mu$ m particle size) from Grace Davison Discovery Sciences Corp (Deerfield, IL). An isocratic mobile phase was used consisting of 25 mM monobasic sodium phosphate with the pH lowered to 2.5 with 17% (w/v) orthophosphoric acid. The flow rate of the mobile phase was 1 mL $\cdot$ min $^{-1}$  and the run time was 10 min. The AA signal was detected at 254 nm. The software used for HPLC programming and data collection was Waters Empower 3. A representative chromatogram for the separation AA from a sweetpotato root pith tissue sample is presented in Figure 2.

For thiamin and riboflavin extraction and analysis, sampled tissues were initially frozen with liquid nitrogen and finely crushed with a mortar and pestle. For sweetpotato

skins, 1 g of tissue was placed in a 25-mL erlenmeyer flask and 10 mL of 0.1 M HCl was added. For all other foliar or root tissues, 5 g was transferred into a 250-mL erlenmeyer flask and 50 mL of 0.1 M HCl was added. The mixture was autoclaved for 30 min at 121 °C. It was allowed to cool and the pH was adjusted to 4.5  $\pm$  0.1 with 2 M sodium acetate. In each individual sample, 100 mg of taka-diestase was added followed by gentle manual stirring for 10 s. All samples were then put in an incubator (Innova™ 4000 Incubator shaker; New Brunswick Scientific Co, Inc., Enfield, CT) at 37 °C with agitation speed of 60 rpm for 12 h. The volume was then brought to 25 mL (sweetpotato skins) or 100 mL (all other sweetpotato tissues) with distilled water and filtered through Whatman #4 paper (GE Healthcare Co., Buckinghamshire, U.K.). Three hundred microliters of 0.03 M potassium ferricyanide was added to 5 mL of sample extract followed by 15 s of vigorous manual stirring. The sample extract was placed in the dark for 10 min to reduce thiamin to thiochrome. To prevent degradation of analytical column performance, the pH of the sample was then adjusted to 7.0 with a 17% orthophosphoric acid solution followed by filtration through a Phenex 0.45- $\mu$ m nylon membrane syringe filter (Phenomenex Inc.) and injected in the HPLC system for simultaneous determination of thiamin and riboflavin. The analysis of thiamin and riboflavin was conducted by HPLC with a reverse phase Synergy Hydro-RP, C18 column (150 mm  $\times$  4.6 mm, 4- $\mu$ m particle size) (Phenomenex Inc.). Column temperature was kept at 32 °C during analyses. The mobile phase consisted of a gradient of two solvents: 1) 20 mM potassium phosphate in 0.1% hexane sulfonic acid; and 2) acetonitrile. The optimal gradient was 97:3 (Solvent 1 and 2, respectively) from 0 to 3 min followed by a uniform transition to 70:30 from 3 to 18 min and a reverse uniform transition back to 97:3 from 18 to 22 min. The flow rate was 1.5 mL $\cdot$ min $^{-1}$  and the total chromatographic run time was 25 min. The sample injection volume was 50  $\mu$ L. A scanning fluorescence (Model 474; Waters Corp.) detector was used for analyte quantification and programmed for a two-event run with a 360:430 excitation:emission wavelength from 0 to 15.3 min followed by 420:525 during the remainder of the run. A representative chromatogram for the separation thiamin and riboflavin from a sweetpotato root pith tissue extract is presented in Figure 3.

The extraction and analysis methodology for vitamin B<sub>6</sub> was adapted from Kall (2003). Tissues were initially frozen with liquid nitrogen and finely crushed with a mortar and pestle. For sweetpotato skins, 1 g of tissue was placed in a 25-mL erlenmeyer flask and 10 mL of 0.1 M HCl was added. For all other foliar or root tissues, 5 g was transferred into a 250-mL erlenmeyer flask and 50 mL of 0.1 M HCl was added. The mixture was autoclaved for 15 min at 121 °C. It was allowed to cool at room temperature for 15 min and the pH was adjusted to 4.5  $\pm$  0.1 with 2 M sodium acetate. The volume was then brought to 25 mL (sweetpotato skins) or 100 mL (all other foliar and root tissue types) with distilled water and then vigorously agitated for 15 s. Twenty-five milliliters were

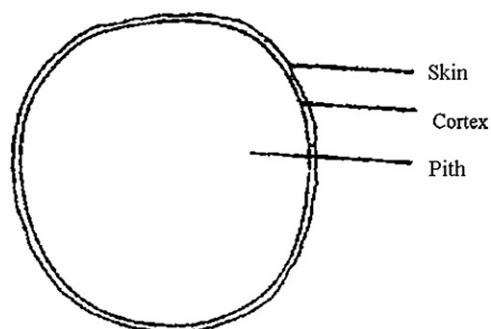


Fig. 1. Diagrammatic representation of sweetpotato root tissue types.

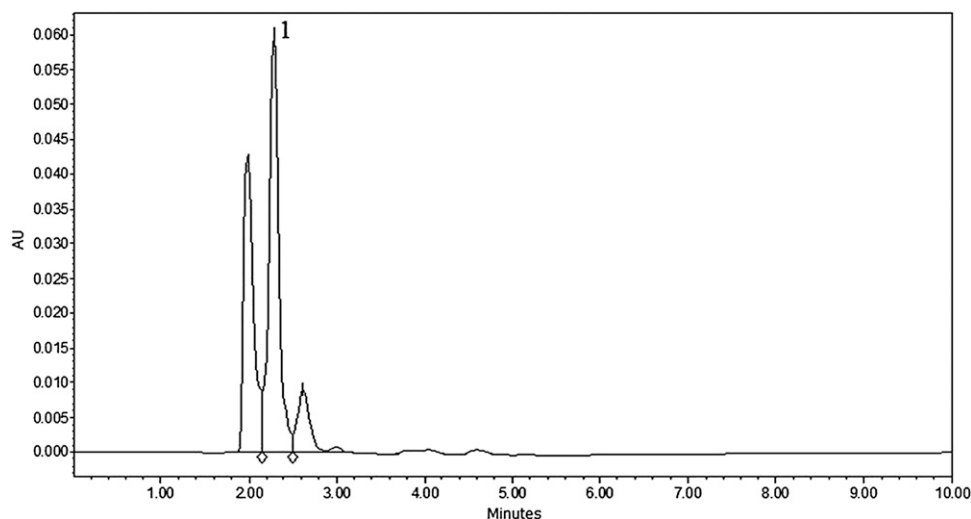


Fig. 2. Representative high-performance liquid chromatogram of ascorbic acid separated from a sweetpotato root pith tissue sample. Identified peaks: ascorbic acid (1).

transferred to a 50-mL test tube. The sample was then centrifuged at  $12,857 \times g$  for 10 min. An aliquot of 15 mL of supernatant was transferred to a 25-mL volumetric flask, and 1 mL of  $25 \text{ U}\cdot\text{mL}^{-1}$  acid phosphatase solution plus 3 mL of  $45 \text{ U}\cdot\text{mL}^{-1}$  of the  $\beta$ -glucosidase solution were added. The sample was incubated at  $37^\circ\text{C}$  with gentle stirring for 18 h. To stop the incubation, the sample was cooled to room temperature, 5 mL of 1 M HCl solution was added, and the flask was filled to the line (25 mL) with 0.1 M HCl. An aliquot of the sample was filtered with a  $0.45\text{-}\mu\text{m}$  nylon membrane syringe filter and transferred to an HPLC vial.

The HPLC analysis of vitamin B<sub>6</sub> was conducted with a reverse phase C-18 HyperClone BDS column (150 mm  $\times$  4.6 mm, 3- $\mu\text{m}$  particle size) from Phenomenex Inc. An isocratic mobile phase consisting of a mixture of 93% buffer and 7% acetonitrile was used. The buffer was a solution of 2.2 mM 1-octane sulfonic acid in 81 mM potassium dihydrogen

phosphate and 4.0 mM triethylamine adjusted to pH 2.75 with 85% orthophosphoric acid. The flow rate was  $1.0 \text{ mL}\cdot\text{min}^{-1}$  and the total chromatographic run time was 14 min. The sample injection volume was 50  $\mu\text{L}$ . To improve the detector sensitivity, the mobile phase pH was adjusted to 7.5 with a post-column infusion of 0.5M phosphate buffer (pH 7.5) at  $0.3 \text{ mL}\cdot\text{min}^{-1}$  by using a Beckman 110B solvent delivery module (Beckman Instruments Inc., Fullerton, CA). Vitamin B<sub>6</sub> vitamers pyridoxine (PN), pyridoxal (PL), and pyridoxamine (PM) were detected with a Waters Model 474 fluorescence detector programmed for excitation at 333 nm and emission at 375 nm. Total vitamin B<sub>6</sub> was calculated as PN, HCl (pyridoxine hydrochloride) with the following equation:

$$\text{PN, HCl} = \text{PN} + (1.01 \times \text{PL}) + (0.85 \times \text{PM}).$$

The coefficients in the previous equation are the result of different molar weight of PL,

HCl; PM, 2 HCl (monohydrate); and PN, HCl.

A representative chromatogram for the separation of vitamin B<sub>6</sub> vitamers from a sweetpotato root pith tissue sample is presented in Figure 4.

*Statistical analyses.* A completely randomized design was used to analyze the experiments. The data were analyzed with SAS program, PROC GLM procedure (SAS Institute, Cary, NC). Treatment means were separated with Tukey's honestly significant difference test.

## Results and Discussion

*Ascorbic acid.* Differences in total AA content were found between tissue types. Young leaves contained the highest AA content followed by mature leaves and buds. Buds also contained significantly higher AA content relative to root, vine, and petiole tissues (Tables 1 and 2). A wide range in sweetpotato leaf AA content has been reported in previous studies. Our results are similar to those reported for various cultivars grown in Malaysia (Villareal et al., 1979), but less than the levels reported by Mosha et al. (1995). The AA content obtained in mature leaves was also similar to the amounts found by Ishida et al. (2000) in the cultivar Beniazuma. The higher AA found in young leaves is consistent with previous reports that indicated AA is higher in young actively metabolizing tissues. Typically, AA content is lowest in dormant or quiescent cells; it markedly increases under conditions that favor rapid growth and metabolism (Pastori et al., 2003). The higher AA content in leaves compared with other vegetative tissues was associated with its importance as a free radical quencher in the high oxidative environment that accompanies photosynthesis (Foyer et al., 1994).

The results confirm previous studies that sweetpotato foliar tissues are a good source

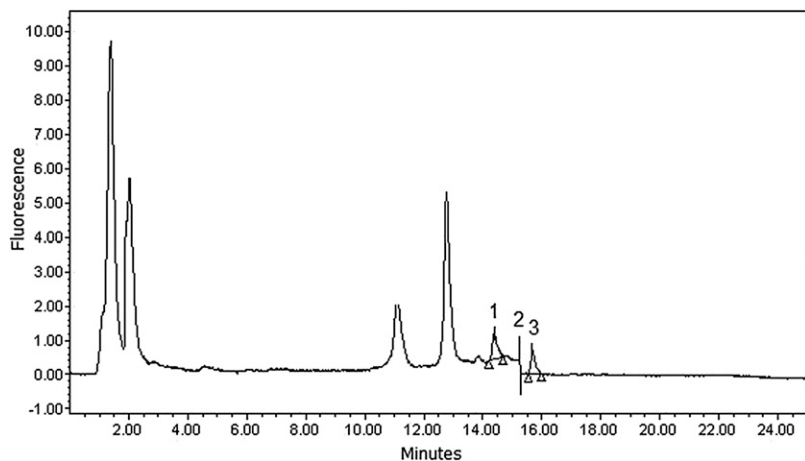


Fig. 3. Representative high-performance liquid chromatogram of thiamin and riboflavin separated from a sweetpotato root pith tissue sample. Identified peaks: thiamin (1), signal from fluorescence detector excitation: emission wavelength change (2), riboflavin (3).

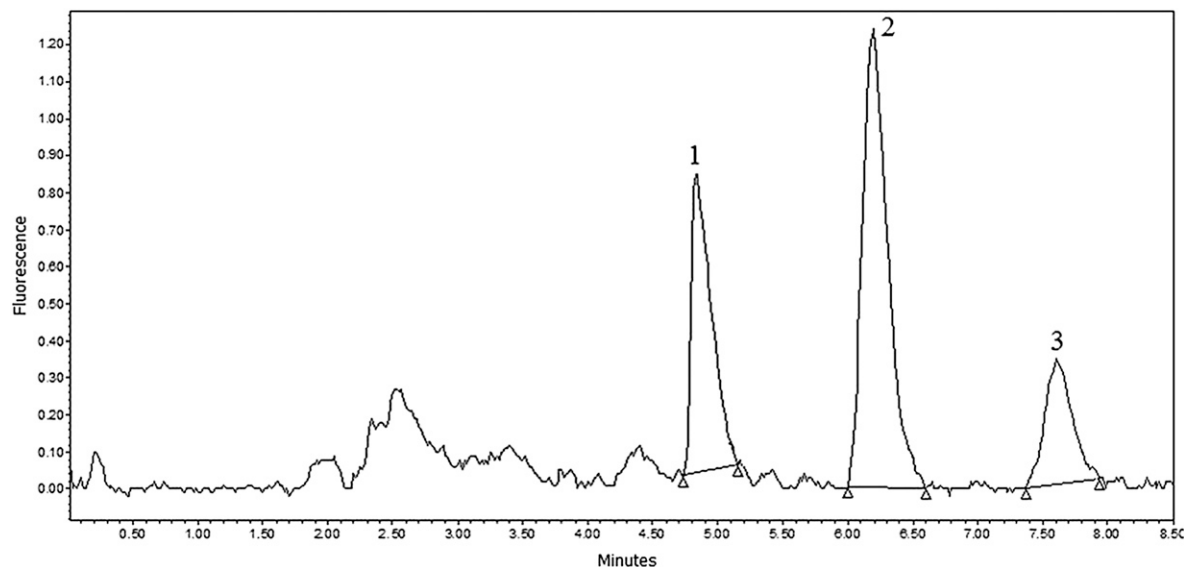


Fig. 4. Representative high-performance liquid chromatogram of vitamin B<sub>6</sub> vitamers, separated from a sweetpotato root pith tissue sample. Identified peaks: pyridoxal (1), pyridoxine (2), pyridoxamine (3).

Table 1. Water-soluble vitamin content in various tissue types of 'Beauregard' sweetpotato (first experiment, 2012).

Tissue type	Ascorbic acid (mg/100 g)	Thiamin (mg/100 g)	Riboflavin (mg/100 g)	Vitamin B <sub>6</sub> (mg/100 g) <sup>y</sup>			
				PL	PN	PM	B <sub>6</sub> <sup>x</sup>
Bud	49.5 c <sup>z</sup>	ND	0.160 c	0.138 a	0.102 b	0.033 c	0.270 c
Vine	15.2 e	ND	0.065 e	0.038 c	0.044 d	ND	0.082 e
Young petiole	22.5 d	ND	0.112 d	0.056 b	0.043 d	ND	0.099 e
Young leaf	121.0 a	ND	0.270 b	0.117 a	0.065 c	0.078 b	0.249 c
Mature petiole	7.7 f	ND	0.034 f	0.011 d	0.364 a	0.001 d	0.376 b
Mature leaf	88.0 b	ND	0.407 a	0.134 a	0.280 a	0.170 a	0.560 a
Root	15.9 e	0.042	0.041 f	0.047 bc	0.112 b	0.005 d	0.164 d

<sup>z</sup>Mean values for ascorbic acid, thiamin, and riboflavin represent the average of six replicates.

<sup>y</sup>Mean values for vitamin B<sub>6</sub> vitamers represent the average for four replicates. Means with different letter within the same column were significantly different ( $P < 0.05$ ) according to Tukey's honestly significant difference test. All units were calculated in mg/100 g fresh weight.

<sup>x</sup>Vitamin B<sub>6</sub> calculated as PN, HCl: PN + (1.01 × PL) + (0.85 × PM).

PL = pyridoxal; PN = pyridoxine; PM = pyridoxamine; ND = not detected.

Table 2. Water-soluble vitamin content in various tissue types of 'Beauregard' sweetpotato (second experiment, 2013).

Tissue type	Ascorbic acid (mg/100 g)	Thiamin (mg/100 g)	Riboflavin (mg/100 g)
Bud	66.8 c <sup>z</sup>	ND	0.130 c
Vine	25.7 d	ND	0.055 d
Young petiole	26.9 d	ND	0.156 b
Young leaf	116.3 a	ND	0.178 b
Mature petiole	10.4 e	ND	0.025 e
Mature leaf	89.7 b	ND	0.242 a
Root	26.9 d	0.038	0.018 e

<sup>z</sup>Mean values for ascorbic acid, thiamin, and riboflavin represent the average of five replicates. Means with different letter within the same column were significantly different ( $P < 0.05$ ) according to Tukey's honestly significant difference test. All units were calculated in mg/100 g fresh weight.

ND = not detected.

of AA (Johnson and Pace, 2010; Maeda and Salunkhe, 1981) and that young leaves have the highest foliar AA content. The AA content (121.0 mg/100 g fresh weight in the first experiment and 116.3 mg in the second experiment) in young sweetpotato leaves compares favorably with other vegetables, including spinach (31.6 mg), green beans (15.8 mg), peas (30.9 mg) (Favell, 1998), fresh broccoli (96.7 mg), fresh cabbage (42.3 mg), fresh collards (92.7 mg), and potatoes (11.0 mg), which are all considered good sources of AA in the diet (Vanderslice et al., 1990).

**Thiamin.** No thiamin was detected in foliar tissues. This contrasts with other authors, who have reported variable amounts in sweetpotato leaves (Ishida et al., 2000; Mosha et al., 1995; Mosha and Gaga, 1999). The lack of thiamin in our results might be explained by cultivar differences. Thiamin content was particularly low in sweetpotato foliage of the cultivar TU-82-155 (mean  $0.02 \pm 0.017$  mg/100 g dry weight basis) in greenhouse beds (Almazan et al., 1997). Unlike AA, it is unclear whether thiamin content is associated with actively photosynthesizing tissues. Additional thiamin analyses in various cultivars are necessary to explain the wide variability in thiamin content reported in foliar tissues.

**Riboflavin.** Riboflavin content differed with tissue type but was consistently higher in leaves. Mature leaves contained higher amounts of riboflavin than young leaves and other plant tissues, including roots (Tables 1 and 2). These results agree with previous reports indicating leaves are a good source of riboflavin. A portion of 85 g of cooked sweetpotato leaves can provide 15% of the

daily intake requirements for an adult and nearly 30% for a child (Woolfe, 1989). Our results indicate that riboflavin in sweetpotato leaves compares favorably with other fruit and vegetables including cassava leaves (0.33 mg), sweet basil (0.33 mg), and papaya (0.30 mg) (Caldwell and Enoch, 1972) and with spinach (0.15 mg), potatoes (0.05 mg), and carrots (0.05 mg) (Hanif et al., 2006). The riboflavin content found in the mature leaves was similar to values previously reported Caldwell and Enoch (1972). The riboflavin content in young leaves and vines was generally similar to results obtained by Ishida et al. (2000).

Riboflavin has been previously found to be more concentrated in green leafy tissues than other plant parts. Riboflavin concentration was at least 3.5 times higher in cassava leaves than roots (Montagnac et al., 2009). The reason for the higher concentration of riboflavin in leaf tissues in this study might be related to the biological roles of this vitamin in plants. In addition to being the precursor of flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD), riboflavin is an essential cofactor for many enzymes in multiple cellular processes such as the citric acid cycle and cellular redox reactions (Jordan et al., 1999). Riboflavin has also been found to be involved in light-dependent processes such as photosynthesis and phototropism (Massey, 2000).

**Vitamin B<sub>6</sub>.** Leaf tissue also contained higher total vitamin B<sub>6</sub> content compared with other tissues. Mature leaves contained 3.4 times higher vitamin B<sub>6</sub> than roots, whereas mature petioles contained 2.3 times more than roots. Bud tissue and young leaves

also contained higher B<sub>6</sub> levels than roots, whereas the vine and young petiole tissue contents were lower than roots (Table 1). Differences in vitamin B<sub>6</sub> content in various sweetpotato tissues have been previously reported with the extent of these differences dependent on cultivar. Leaf tissue of the cultivar Koganesengan contained 9.1 times higher vitamin B<sub>6</sub> content than root tissue, whereas leaf tissue of the cultivar Beniazuma contained only 1.1 times more than root tissue (Ishida et al., 2000). Vitamin B<sub>6</sub> content in mature petioles in this study was higher than the value reported by Ishida et al. (2000); however, the vitamin B<sub>6</sub> content found in young petioles was lower.

The contents of individual B<sub>6</sub> vitamers were variable among foliar tissues. PL was found in higher amounts in mature leaves and mature petioles and lower in young petioles and vines. PN content was higher in mature petioles and mature leaves and lower in vines. Meanwhile, PM was higher in mature leaves and lower in roots. No previous reports were found on vitamin B<sub>6</sub> vitamers in sweetpotato leaves. Total vitamin B<sub>6</sub> composition of roots consisted of 29% PL, 68% PN, and 3% PM. These results contrast with a previous report indicating total vitamin B<sub>6</sub> of sweetpotato roots was 44% PL, 33% PN, and 23% PM (Kwiatkowska et al., 1989). This discrepancy may be the result of cultivar differences.

The reason for the higher concentration of vitamin B<sub>6</sub> found in leaves may be associated with its important physiological role in actively photosynthesizing tissues. Vitamin B<sub>6</sub> has been implicated in photo-oxidative protection in *Arabidopsis thaliana* by limiting O<sub>2</sub> accumulation under high light conditions and by preventing O<sub>2</sub>-mediated oxidative damage (Havaux et al., 2009).

The results of this study indicate mature and young leaves could provide significant amounts of vitamin B<sub>6</sub> to the diet. The vitamin B<sub>6</sub> content found in sweetpotato leaves compares favorably with other fruits and vegetables, including raw broccoli (0.17 mg), fresh avocados (0.44 mg), raw carrots (0.170 mg), bananas (0.31 mg/100 g), and cauliflower (0.16 mg) (Kabir et al., 1983).

**Water-soluble vitamin content in root tissues.** Limited studies have been conducted on the AA content in different sweetpotato root tissues, although tissue differences in other fruits and vegetables have been widely

Table 3. Water-soluble vitamin content in 'Beauregard' and 'LA 07-146' sweetpotato root tissue.<sup>z</sup>

	Tissue/part	Ascorbic acid (mg/100 g)	Thiamin (mg/100 g)	Riboflavin (mg/100 g)	Vitamin B <sub>6</sub> (mg/100 g)			
					PL	PN	PM	B <sub>6</sub> <sup>y</sup>
LA 07-146	Skin	3.2 c <sup>e</sup>	0.012 c	0.06 a	0.040 a	0.032 c	0.0053 b	0.08 c
	Cortex	16.0 ab	0.016 c	0.014 d	0.030 bc	0.131 b	0.0573 a	0.21 b
	Proximal	17.0 a	0.035 b	0.024 b	0.034 ab	0.173 a	0.0506 a	0.25 a
	Distal	15.5 b	0.046 a	0.019 c	0.026 c	0.178 a	0.0349 a	0.23 ab
	Pith	16.0 ab	0.05 a	0.022 bc	0.029 bc	0.158 ab	0.0533 a	0.23 ab
Beauregard	Skin	3.8 b	0.031 bc	0.122 a	0.052 a	0.023 c	0.0078 a	0.081 c
	Cortex	13.4 a	0.056 a	0.035 c	0.050 a	0.152 a	0.0065 a	0.21 a
	Proximal	19.4 a	0.025 c	0.050 b	0.061 a	0.105 b	0.0069 a	0.17 ab
	Distal	17.6 a	0.031 bc	0.040 bc	0.053 a	0.090 b	0.0047 a	0.15 b
	Pith	15.0 a	0.038 b	0.041 bc	0.047 a	0.112 ab	0.0047 a	0.16 ab

<sup>z</sup>All results are presented in mg/100 g of fresh weight basis.

<sup>y</sup>Vitamin B<sub>6</sub> calculated as PN, HCl: PN + (1.01 × PL) + (0.85 × PM).

<sup>x</sup>Means within the same cultivar and column followed by different letters were significantly different ( $P < 0.05$ ) based on Tukey's honestly significant difference test. All vitamin content represent the average of six individual roots.

PL = pyridoxal; PN = pyridoxine; PM = pyridoxamine.

reported (Erdman and Klein, 1982). The AA content among root tissues was similar between the cortex and all of the pith tissues in this study (Table 3). The AA content was lower in skin tissue. No differences in AA content were observed between small and large sweetpotato roots (Reddy and Sistrunk, 1980). Proximal end tissue contained lower AA content than the central section and the distal end in roots stored at 15.5 °C, but this difference disappeared in roots exposed to 29 °C for 8 and 15 d (Ezell et al., 1952). The results for two cultivars in this study indicated skin tissue contained lower amounts of AA compared with cortex and all of the pith locations (Table 3). The lower AA content found in skin might be the result of the skin (periderm) cell's structure and function. The sweetpotato skin is composed of three layers: phellem, phelloderm, and phellogen (cork cambium). The phellogen is a lateral meristem that is responsible for secondary growth, producing the phelloderm (living parenchyma cells) toward the inside of the root and the phellem (cells that die to form protective tissue) toward the outside (Firon et al., 2009). The outer skin cells are devoid of starch granules, become partly lignified during growth and are progressively sloughed off (Villavicencio et al., 2007). The phellogen layer remains active until harvest with its activity maintaining a constant thickness of the periderm layer (Firon et al., 2009). The relatively lower proportion of metabolically active cells in skin may contribute to their lower AA content. Lower AA was also found in potato peels relative to the inner flesh (Augustin et al., 1979).

Thiamin differences were observed among root tissues, but the differences were not consistent across cultivars. Thiamin content was higher in the distal and central pith regions of the root and lowest in cortex and skin in cultivar LA 07-146. Thiamin was higher in the cortex and lowest in the proximal end and skin in 'Beauregard' roots. Information on thiamin distribution within root tissues is limited. A previous report found thiamin content to be twice as high 2 to 3 mm below the skin in comparison with the center portion of the root in sweetpotato cultivars from the South Pacific (Bradbury

and Singh, 1986). Our results are consistent with the lower thiamin content found in potato peel tissue compared with the flesh (Augustin et al., 1979). Because thiamin is a coenzyme involved in multiple metabolic reactions, the lower thiamin content found in skin tissue may be related to the relatively low amount of metabolically active cells.

Riboflavin content was consistently higher in skin tissue relative to the other root tissues in both cultivars. Riboflavin content was lowest in cortex in cultivar LA 07-146, whereas in 'Beauregard', the cortex tissue was not lower in riboflavin compared with the distal end and central pith tissue. Riboflavin content was also found to be similar within different internal root locations of other sweetpotato cultivars (Bradbury and Singh, 1986). Riboflavin content was also found to be higher in potato peel tissue compared with flesh tissue (Augustin et al., 1979). The higher riboflavin in skin tissue could be related to its role in the synthesis of lignin and antimicrobial compounds. Riboflavin functions as an essential component of FAD and FMN. Numerous flavoprotein enzymes present in plant tissue are known to bind FAD and FMN (Zhuang and Barth, 2003). These flavoenzymes include many oxidases, dehydrogenases, and enzymes involved in the synthesis of aromatic amino acids, quinones, lignin, flavonoids, and alkaloids (Zhuang and Barth, 2003). Although riboflavin was higher in skin tissue relative to other root tissues, it is unlikely skin tissue would be a good source of riboflavin in the diet as a result of the lack of consumption of sweetpotato skin tissue.

Vitamin B<sub>6</sub> content was consistently lower in skin tissue in both sweetpotato cultivars. The vitamin B<sub>6</sub> content in the other tissue types varied with cultivar. Among the vitamin B<sub>6</sub> vitamers, PL and PN contents were different among root tissues, but these differences were not consistent across cultivars. Except for a lower PM content in skin tissue in cultivar LA 07-146, the PM content was mostly similar across tissues of cultivar LA 07-146 and 'Beauregard'. In general, PN was predominant in the pith of the different root locations and in the cortex. No previous reports were found comparing the vitamin B<sub>6</sub>

content between root tissue types. The lower vitamin B<sub>6</sub> content found in skin tissue might be the result of similar reasons as discussed for AA and thiamin. Vitamin B<sub>6</sub> is a coenzyme component of numerous larger enzymes, the majority of which are involved in amino acid metabolism (Zhuang and Barth, 2003). General types of enzymatic reactions catalyzed by vitamin B<sub>6</sub> include transamination, decarboxylation, transulfhydration and desulfhydration, cleavage, and racemization (Zhuang and Barth, 2003).

In conclusion, among the different sweetpotato tissues, the AA, riboflavin, and vitamin B<sub>6</sub> contents were higher in leaf tissue. Although no thiamin was found in sweetpotato foliar tissues, the results of this study confirmed that leaf tissue is a potentially good source of multiple WSV in human diet. Sweetpotato root tissues showed a variable distribution of WSV. In general, skin contained a lower level of AA, thiamin, and vitamin B<sub>6</sub> and higher riboflavin content. All other differences in WSV found in root tissues were cultivar-dependent.

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